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THESIS

THE EFFECTS OF THE JOINT MULTI-MISSION ELECTRO-OPTICAL SYSTEM ON LITTORAL MARITIME INTELLIGENCE, SURVEILLANCE, AND RECONNAISSANCE OPERATIONS

by

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and
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September 2009

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13. ABSTRACT (maximum 200 words)

The United States Department of Defense finds itself in a period of reduced resources and growing requirements. In the field of Intelligence, Surveillance, and Reconnaissance (ISR), there have been calls for both manpower and system cuts, while collection requirements continue to increase. One proposed method for maximizing ISR collection efforts is the development of multi-mission capable collection equipment. In support of this concept, BAE Systems has developed the Joint Multi-Mission Electro-optical System (JMMES). Designed for potential use on both manned and unmanned aircraft, JMMES is capable of multi-mission integration and target prosecution without the need to exchange system components or system operator, thus increasing flexibility, responsiveness, and capabilities, while reducing manning and cost requirements. JMMES incorporates multi-spectral technology and advanced search algorithms to enhance autonomous collection capabilities.

Our thesis investigates how a JMMES equipped SH-60 variant aircraft affects U.S. ISR capabilities in the littoral regions, specifically in the areas of Anti Submarine Warfare (ASW), Surface Warfare (SUW), Maritime Interdiction Operations (MIO), and Search and Rescue (SAR). We teamed with the faculty research group in conducting JCTD test flights during Trident Warrior 2009. Utilizing both quantitative and qualitative results and analysis from the exercise flights and post-flight surveys, we developed an organizational simulation model, using VDT, to evaluate the benefits of JMMES.

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Our thesis investigates how a JMMES equipped SH-60 variant aircraft affects U.S. ISR capabilities in the littoral regions, specifically in the areas of Anti Submarine Warfare (ASW), Surface Warfare (SUW), Maritime Interdiction Operations (MIO), and Search and Rescue (SAR). We teamed with the faculty research group in conducting JCTD test flights during Trident Warrior 2009. Utilizing both quantitative and qualitative results and analysis from the exercise flights and post-flight surveys, we developed an organizational simulation model, using VDT, to evaluate the benefits of JMMES.

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LIST OF ACRONYMS AND ABBREVIATIONS

ACF	Anti Coalition Fighter
AF	Automated Features
AoI	Area of Interest
ASG	Abu Sayaff Group
AS&C	Advanced Systems and Concepts
ASW	Anti Submarine Warfare
AVT	Automatic Video Tracking
BPM	Business Process Modeling
C2	Command and Control
CCC	Counter Canopy and Concealment Operations
CG(X)	Next generation U.S. Navy Aircraft Carrier
CIED	Counter Improvised Explosive Device
CISR	ISR Operations Support
CNO	Chief of Naval Operations
CoE	Concept of Employment
COI	Critical Operational Issues
CRS	Congressional Research Service
CSAR	Combat Search and Rescue
CSG	Carrier Strike Group
DD(X)	Next Generation U.S. Navy Destroyer
DED	Demonstration Execution Document
DISE	Distributed Information and Systems Experimentation
DoD	Department of Defense
DoN	Department of the Navy
DUSD	Deputy Undersecretary of Defense
EM	Electro Magnetic
EO	Electro Optic
EON	Electro Optic Narrow
EOW	Electro Optic Wide
EPAS	Electro Optic Passive Anti Submarine Warfare
ESM	Electronic Support Measures
FLIR	Forward Looking Infrared
FMS	Flight Management System
FSD	Full Spectrum Dominance
FY	Fiscal Year
GDP	Gross Domestic Product
GPS	Global Positioning System

GUI	Graphical User Interface
GWOT	Global War on Terror
HSI	Hyper Spectral Imagery
HS	Human System Interaction
IAP	Integrated Assessment Plan
IC	Intelligence Cycle
ICD	Interface Control Document
ICD	Illicit Crop Detection
IED	Improvised Explosive Device
IMB	International Maritime Bureau
IN	Intelligence Need
INSS	Institute for National Security Studies
IR	Infrared
IRG	Iranian Revolutionary Guard
ISPS	International Ship and Port Facility Security
ISR	Intelligence Surveillance and Reconnaissance
JCS	Joint Chiefs of Staff
JCTD	Joint Capability Technology Demonstration
JLLS	Joint Lessons Learned System
JMMES	Joint Multi Mission Electro-Optic System
JP	Joint Publication
LAMPS	Light Airborne Multi-Purpose System
LCS	Littoral Combat Ship
LD	Laser Designator
LRF	Laser Range Finder
MA	Mission Area Support
MAD	Magnetic Anomaly Detector
MCM	Mine Countermeasures
MEDEVAC	Medical Evacuation
MHT	Multi Hypothesis Tracking
MIO	Maritime Interdiction Operations
MISR	Maritime ISR
MPA	Maritime Patrol Aircraft
MSAR	Maritime Search and Rescue
MSI	Multispectral Imaging
MTS-B	Multispectral Targeting System Bravo
MUA	Military Utility Assessment
MV	Motor Vessel
MWIR	Medium Wave Infrared
NCW	Network Centric Warfare

NNWC	Naval Network Warfare Command
NPS	Naval Postgraduate School
NSW	Navy Special Warfare
NWC	Naval War College
OPAREA	Operating Area
OTA	Operational Test Agent
PGM	Precision Guided Munitions
R&D	Research and Development
RADAR	Radio Detection and Ranging
RFP	Request for Proposal
SA	Situational Awareness
SAR	Search and Rescue
SECDEF	Secretary of Defense
SECNAV	Secretary of the Navy
SLOC	Sea Line of Communication
SM	In-flight System Management
SME	Subject Matter Expert
SUW	Surface Warfare
TACREP	Tactical Report
TS	Target Situation Awareness
TTP	Tactics, Techniques, and Procedures
TW09	Trident Warrior 2009
U.S.	United States
UAS	Unmanned Aircraft System
USCG	United States Coast Guard
USN	United States Navy
USS	United States Ship
UV	Ultraviolet
VACAPES	Virginia Capes
VDT	Visual Design Team
VERTREP	Vertical Replenishment

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I. INTRODUCTION

A. INTRODUCTION

The United States military has entered a period of constrained budgets and increasing operational commitments against a diverse set of adversaries. These adversaries employ unique and evolving tactics, such as suicide bomber attacks, improvised explosive devices (IEDs), and loosely connected networks, all designed to avoid United States (U.S.) dominance in mass on mass engagements. To achieve success in this challenging period, U.S. forces must counter the adversary’s attempts to avoid detection and engagement by advanced weapons systems. As such, it has become increasingly difficult, yet vitally important, to maintain a situational awareness (SA) advantage. In order to achieve this end, new sensor technologies and operational employment techniques must continue to be sought.

B. OVERVIEW

Many of the conflicts in the Global War on Terror (GWOT) provide evidence of adversaries increasing their abilities to avoid detection and targeting by U.S. forces. During the period from 2004 to 2007, the ubiquitous use of IEDs in Iraq produced numerous U.S. coalition casualties. This technique has become quite successful for anti-coalition fighters (ACF) due to the difficulty in discriminating IEDs and those emplacing them from the non-dangerous elements of the environment. In Afghanistan, both Taliban and Al Qaeda forces conducted attacks in challenging mountainous areas that afforded cover and

concealment for their small bands of fighters. Off the coast of Somalia, pirates have utilized small fast-boats to hijack ships on the open seas. These are just a few examples of the challenges confronting U.S. forces around the globe. In all cases, the adversary has attempted to avoid decisive mass-on-mass engagements and has instead sought to remain unnoticed prior to attacking.

When U.S. forces are able to detect an adversary prior to an attack, the results are overwhelmingly in favor of the United States. U.S. forces in Iraq have found success using electro optical (EO) and infrared (IR) sensors to detect ACF emplacing IEDs, resulting in a lethal strike from a precision guided munitions (PGM). In Afghanistan, terrorist leaders have been tracked and killed by strikes from Predator unmanned aircraft systems (UAS) equipped with EO/IR sensors and PGMs. For maritime interdiction operations (MIO), aircraft equipped with EO/IR sensors provide vital information that affords validation of targets and awareness of the operating environment. By taking away the enemy's ability to hide, U.S. forces are able to greatly reduce the advantage sought by adversaries.

In order to achieve the desired detection of enemy combatants, the intelligence community utilizes an assortment of Intelligence, Surveillance, and Reconnaissance (ISR) sensors. These sensors vary according to operating environments and specific detection requirements, and are typically designed to operate in EO, IR, or radio bands of the electromagnetic (EM) spectrum.

Each individual band of the EM spectrum has unique advantages and disadvantages depending on a variety of

factors, including atmospheric attenuation, target distance, and target cross-section. As EM energy propagates from the object to the detecting sensor, the atmosphere attenuates the signal. The amount of attenuation that occurs varies with frequency. Figure 1 depicts how atmospheric attenuation affects EM frequencies. The horizontal axis shows the frequency range of the EM energy, as well as the associated wavelength, while the vertical axis shows the atmospheric attenuation that occurs at the given frequency.

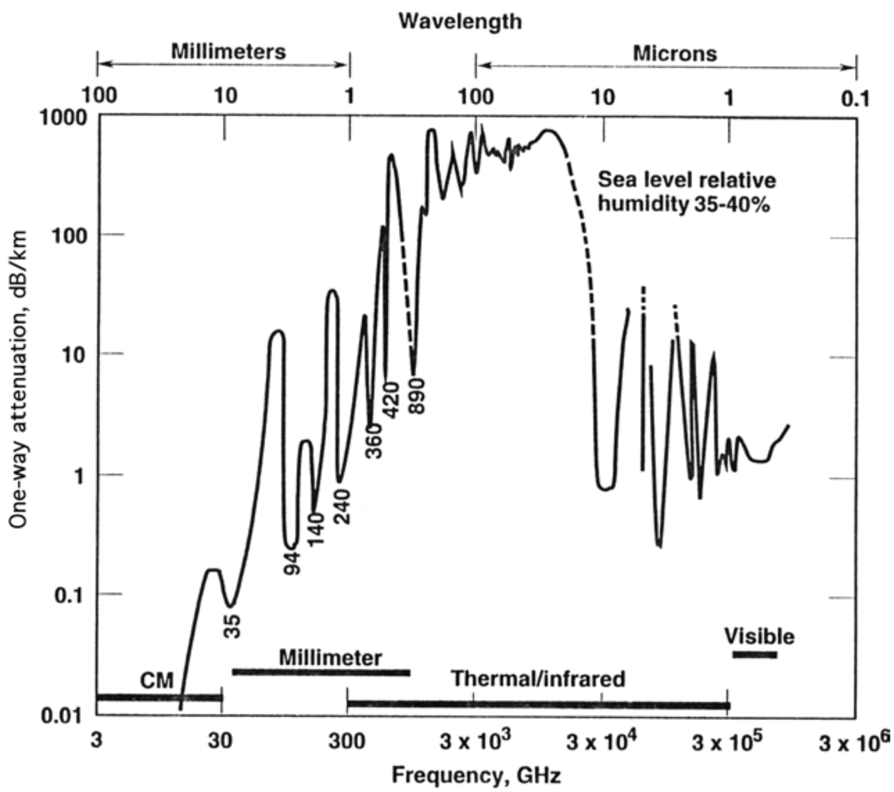

Figure 1. Atmospheric Attenuation Across EM Spectrum[1]

[1] Christian Ho, NASA "Radio Wave Propagation Handbook for Communication on and Around Mars," http://descanso.jpl.nasa.gov/Propagation/mars/MarsPub_sec4.pdf, accessed 15 September 2009.

EO and IR sensors are passive devices that rely on the detection of the radiations emitted by the target.[2] EO systems perform very well in daylight conditions and provide detail that allows for positive identification of targets. However, EO systems perform poorly in darkness and are susceptible to obscurants in the air such as smoke, smog, clouds and dust. IR systems are capable of imaging objects without need for solar illumination and through some obscurants that adversely affect EO systems. However, IR systems are not capable of providing as high a degree of image detail as EO systems. EO and IR systems both have maximum operational ranges of a few kilometers.

Conversely, Radio Detection and Ranging (RADAR) systems are active sensors that emit energy that is reflected from targets. RADAR systems perform equally well during day or night conditions and suffer less atmospheric attenuation than EO or IR systems. As such, they are capable of much greater ranges. Utilizing RADER systems to direct EO/IR sensors directly to targets allows for hi-resolution imagery in less time than if EO/IR sensor was conducting an independent search for target. By carefully selecting the mix of sensors, the probability of detection of adversaries increases.

The information collected by these sensors must undergo some degree of analysis and culling, to provide end-users with pertinent information. Analysis can be done by either computer systems, humans, or a combination of

[2] A. Nejat Ince, Ercan Topuz, Erdal Panyirgi,Cevdet Isik: Principles of Integrated Maritime Surveillance Systems (Kluwer Academic Publishers: Boston, 2000), 125.

both. The time required for analysis varies by ISR system due to the varied amount and type of information collected.

EO/IR systems produce images that must be scanned for recognizable patterns of targets. Computers have an ability to continually scan imagery for long periods of time without risk of degraded performance due to boredom or fatigue. Humans posses a greater capability to pattern match visual images, but they are susceptible to performance errors. Combining computer and human analysis allows for the benefits of each system to be utilized resulting in enhanced capabilities. The analysis of EO/IR images can be done at the location of the sensor or at a central location

After the information has been collected and analyzed, it must be disseminated to end-users. The end-users are typically military commanders or small-unit leaders who utilize information from the ISR process to develop and maintain SA. The dissemination process requires that information be transmitted between sensors, operator, analysts, and finally to the end user. Each re-transmission of the information presents the possibility for delay, or degradation, as well as increased manpower requirements. Looking at the dissemination process from a systems-analysis perspective, there is room for modification and improved performance.

In examining the process of obtaining and disseminating ISR information, it is evident that the ISR process is a complex system-of-systems. Each element is susceptible to adverse effects ranging from an adversary’s detection avoidance techniques to dissemination delays. If

the interrelationships of the systems are not considered, a seemingly simple change can result in degraded performance of the entire ISR process. Improved understanding of the various systems in the ISR process allows for modifications that can yield significant performance improvements. We will examine the ISR process in more detail in Chapter II.

C. CHALLENGE OF MAINTAINING ISR CAPABILITIES

In order to maintain ISR capabilities as adversaries, and operating environments change, the U.S. Department of Defense (DoD) continually seeks improvements to existing equipment, as well as new innovations. The U.S. Deputy Under Secretary of Defense, Advanced Systems and Concepts (DUSD/AS&C) helps the DoD seek technological advantages against adversaries by identifying the best operational concepts and technology solutions for transformational, joint, and coalition warfare.[3] One means DUSD/AS&C uses to accomplish this critical function is the Joint Capability Technology Demonstration (JCTD) process.[4] The JCTD process creates a structured method for private industry to demonstrate new operational concepts, utilizing mature or maturing technologies, to solve important military problems. The partnership between private industry and DUSD/AS&C allows for more rapid fielding of new concepts and has proven successful in the conflicts in Iraq and Afghanistan, and GWOT. Before being accepted for use in

[3] Office for the Under Secretary of Defense for Acquisition, Technology and Logistics, "AS&C/JCTD Mission Statement," http://www.acq.osd.mil/jctd/aboutus.html, accessed 15 September 2009.

[4] Ibid.

the DoD, new concepts and equipment must demonstrate an acceptable level of performance in scenarios designed to simulate anticipated missions.

The different services in DoD have unique requirements for ISR system capabilities. Threats to U.S. Navy (USN) ships are increasingly coming from smaller boats operating in highly dispersed or independent manners, as well as mines and other threats with small cross sections. There is also a growing need to engage pirates and smugglers in MIO.

Because the ISR process is a system-of-systems, it is not wise to focus solely on equipment improvements. Innovation must occur in both processing and dissemination. However, the DoD does not have a robust system like the USN JCTD process for these areas. A Joint Lessons Learned System (JLLS) provides a means to share improvement ideas, but it lacks an academically acceptable methodology for evaluating ideas. The DoD also lacks a structured process to predict interaction of system changes on the whole ISR process. The answer for this concern can be found in Business Process Modeling (BPM). By utilizing software and methods from the private sector, the DoD can create a more structured means to improve both processing and dissemination, as well as, predict performance of the entire ISR process.

D. SCOPE

BAE Systems has submitted the Joint Multi Mission Electro-Optic System (JMMES) for consideration as a solution to the military challenge of identifying difficult to detect objects, such as submarines, mines, IEDs, persons, surface vessels, and camouflaged objects. JMMES

leverages computer-processing power and multi-spectral imaging (MSI) in the detection of targets. The multi-sensor turret operating in the EO/IR spectrums, coupled with advanced algorithms, facilitates automated detection, tracking, and targeting. This thesis will be limited to the effects JMMES will have on the maritime ISR process, particularly in the littoral regions.

E. THESIS INTENT

The JCTD process seeks to apply a methodical process evaluate proposed technologies. However, there is no requirement for the JCTD process to analyze how the new technology will affect existing process of the system into which it is introduced. A challenge for U.S. Department of the Navy (DoN) is to improve detection performance while maintaining or improving the capabilities of the ISR system. The DoD’s goal is to increase quality and quantity of ISR available, without increasing costs or manpower requirements, by utilizing systems that have multi-mission capabilities.

By applying survey research and deterministic modeling approach, an understanding of the impacts of the JMMES on the existing Maritime ISR system can be developed.

This thesis will answer two questions:

- How does JMMES' performance of maritime ISR mission compare to fielded systems?
- How will the addition of JMMES to manned Aircraft Systems impact the current performance of maritime ISR?

F. ASSUMPTIONS

JMMES is not expected to conduct independent wide-area search; rather, it provides higher resolution identification, precision location and tracking based on cueing data. Any aircraft system outfitted with JMMES will have cueing provided by a radar system. JMMES will be employed on H-60 variants. As there is potential for future installation onboard UAS, that is not within the scope of this thesis.

G. GEOGRAPHIC BOUNDING

The BPM presented in Chapter IV is based on independent operations of a U.S. ship operating in the littorals.

H. CHAPTER OUTLINE

Chapter I	Introduction
Chapter II	Academic and Technology Review
Chapter III	Data Collection and Analysis
Chapter IV	Maritime ISR Modeling and Analysis
Chapter V	Conclusion and Recommendations

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II. ACADEMIC AND TECHNOLOGY REVIEW

A. TRANSITION OF NAVAL WARFARE

Due to the operational successes of both carrier and submarine based warfare in World War II, the United States had grown accustomed to conducting maritime operations against a known and traditional enemy, specifically a large nation-state with an industrial economy, capable of sustaining and employing a blue-water Naval fleet. While the United States continued to improve its capabilities, incorporating nuclear powered surface and subsurface platforms, the fundamental principle of operations remained constant. While the U.S. Army and Air Force were focused on security challenges ashore, the Navy focused on maritime challenges, particularly blue-water challenges, on the open ocean. With the collapse of the Soviet Union and the ensuing decline in communism at the end of the millennium, the United States was forced to re-examine its maritime posture, as there no longer existed a capable and equal adversary to challenge U.S. blue-water dominance.[5]

One idea developed in this time of re-examination was the concept of “network-centric” warfare (NCW). This concept was born in the mid-1990s, when then vice-chairman of the Joint Chiefs of Staff, Admiral William Owens, published a paper on a system-of-systems in the Institute for National Security Studies (INSS). This system-of-systems concept integrated three elements:

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[5] Loren Thompson, Lexington Institute, “Littoral Combat Ship and the Birth of a New Navy” (comments given April 26, 2007) http://www.defense-aerospace.com/article-view/verbatim/81683/lcs-leads-revolution-in-naval-warfare.html, accessed 15 September 2009.

(1) sensors, satellites, radars, and remote acoustic devices;

(2) computer and communication systems;

(3) modern precision guided weapons.[6]

It merged and combined the concepts of command and control (C2), surveillance, reconnaissance, intelligence, and targeting capabilities.

In 1996, the Joint Chiefs of Staff (JCS) released Joint Vision 2010, in which they presented the new military concept of full spectrum dominance (FSD), the next iteration of Owens' concept. FSD was christened as the "key characteristic for our armed forces in the 21st century."[7] FSD was described as the United States military's ability to dominate the battle space throughout the spectrum that exists from peace operations to the application of full military power. Key to the FSD concept is the idea of information superiority, similarly supported by the system of systems concept.

Over the next two years, the system-of-systems concept and FSD continued to evolve into what is now known as NCW. NCW seeks to translate an information advantage into a competitive war-fighting advantage through the robust networking of dispersed forces.[8] However, in response to perceived diminishing global threats, military spending was

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[6] Christopher Sterling, *Military Communications: From Ancient Times to the 21st Century* (Santa Barbara: ABC-CLIO, 2007), 434.

[7] John Shalikashvili, *Joint Vision 2010*, Joint Chiefs of Staff, July 1996, 2.

[8] Arthur Cebrowski, "The Implementation of Network-Centric Warfare," Office of Force Transformation/Office of the Secretary of Defense, 2005, 4.

gradually reduced throughout the 1990s. As seen in Table 1, military spending, as a percentage of Gross Domestic Product (GDP), dropped 42% over the decade from 1990 to 2000. As a result, NCW remained a future concept throughout the 1990s and was never fully adopted or implemented.

Fiscal Year	Military spending as percent of GDP
1990	5.2
1991	4.6
1992	4.8
1993	4.4
1994	4.0
1995	3.7
1996	3.5
1997	3.3
1998	3.1
1999	3.0
2000	3.0
2001	3.0

Table 1. U.S. Military Spending as a Percentage of Discretionary Spending[9]

The events of September 11, 2001, forced the United States to quickly move forward from a decade of declining funding and examine the required technological innovation and change to successfully combat a new enemy. The death of 3,000 Americans in an attack against two symbols of

[9] Office of Management and Budget, Historical Tables, "Outlays by Superfunction and Function," http://www.truthandpolitics.org/military-relative-size.php#ref-1, accessed 15 September 2009.

American military and economic strength awakened U.S. military and political leadership to an emerging threat and forced it to the forefront.

The threat of terrorism was not new to the United States and existed concurrently with the military funding decline throughout the 1990s, as acts of terrorism were sprinkled throughout the decade. Seventeen Sailors died when terrorists attacked the USS COLE, which had stopped to refuel at a Yemeni port in October 2000. Other terrorist actions against U.S. interests and personnel include the 1998 embassy bombings in Kenya and Tanzania, the 1996 Khobar Tower bombings in Saudi Arabia, and the 1993 World Trade Center bombing. In August 1996, a relatively unknown terrorist, Osama bin Laden, declared war on the United States through an Islamic *fatwa*, or Islamic religious opinion/edict. This was broadened in February 1998, with a second fatwa calling on all Muslims to kill Americans and their allies.[10] All of which came to a head with the tragic events of September 11.

The United States found itself confronted by a new enemy utilizing non-traditional tactics and was faced with the reality that an evolution in military tactics, operations, strategy, and philosophy would be required to successfully defeat this threat. While still having to maintain the capability to fight a conventional, mass-on-mass war, the United States would also need to further develop an unconventional force to successfully combat terrorist and insurgent threats. These groups were highly

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[10] Osama Bin laden, "Declaration of War against the Americans Occupying the Land of the Two Holy Places," *Al Quds Al Arabi*, August 1996.

networked organizations utilizing asymmetric and irregular forms of warfare engagement. As such, an equally irregular and networked force would be required to successfully combat them.

From a maritime perspective, these new threats presented a variety of challenges. First, their asymmetric nature meant they could challenge the United States where it was weak, vice the traditional naval engagement model of strength on strength. Second, the adversary was relatively weak in resources and high-powered weaponry. While this does not initially appear a challenge to confront, under further examination, it becomes clear. Due to limited indigenous resources, these groups relied heavily on commercial technology and adapted it to their needs. Their use of the internet and commercially available communication devices predicated their networked approach and their lack of advanced weaponry and platforms led to their resultant limited geographical focus. Also, these groups did not possess significant operational capability on the high seas. Rather, they focused their efforts in the littoral regions, where population, commerce, and marine traffic were the densest.[11] The Navy was left with a difficult problem: the need to address the aforementioned littoral, brown-water problem while maintaining the capability and readiness for traditional blue-water operations.

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[11] Loren Thompson, Lexington Institute, "Littoral Combat Ship and the Birth of a New Navy," (comments given 26 April 2007) http://www.defense-aerospace.com/article-view/verbatim/81683/lcs-leads-revolution-in-naval-warfare.html, accessed 15 September 2009.

The Navy could see a broader array of responsibility and mission areas for the fleet operating in littoral areas but was confronted with the question of how to properly reorganize forces and develop strategy to operate successfully in the littoral regions. While the Navy was not ready to rule out deploying large warships to support these littoral operations, it was obvious that these were not the ideal platforms to conduct the needed operations. Rather, there was a need for a new, agile platform, designed specifically for operations in the shallow, crowded, and challenging littoral regions. Utilizing the fundamental principles of NCW, these new ships would reduce the threat to larger warships as they conducted highly networked and responsive operations against this new adversary. Thus, the rightfully named Littoral Combat Ship (LCS) was born.

B. LITTORAL OPERATIONS

In this section, we will examine specific challenges and threats that exist in the littoral regions. Additionally, we will examine the primary maritime and maritime-based manned-airborne platform to be utilized in this environment.

1. Threats in Littoral Regions

Compared to operations on the open seas, conducting operations within the littoral regions of the world creates a unique set of challenges and threats. Often, these challenges are predicated by the close proximity to land, restricted operating water depths, and high traffic/restricted maneuver areas of the littoral regions.

These challenges consist of piracy, terrorist attacks, swarm tactics, and littoral ASW operations.

a. Piracy

One significant littoral threat that has received a great deal of media coverage as of late is piracy. Maritime piracy is defined by the United Nations as “any criminal act of violence, detention, or depredation committed for private ends by the crew or the passengers of a private ship or aircraft that is directed on the high seas against another ship, aircraft, or against persons or property on board a ship or aircraft.”[12] Various other definitions exist, but can be compiled to convey piracy as of acts of kidnapping, robbery, murder, seizure, and sabotage.

Maritime piracy focused against commercial transport vessels is a significant international concern due to the globalization and interconnectedness of the world economy. Over 50,000 ships transit international waterways annually and it is estimated that over $13 billion dollars are lost each year due to pirate actions.[13] Common areas traditionally vulnerable to piracy include the Red Sea, Indian Ocean, Horn of Africa, and the Strait of Malacca. Modern piracy techniques include agile, networked, small boats focusing their efforts on shipping

[12] Article 101, Section 1, Part VII, United Nations Convention on the Law of the Sea, December 10, 1982.

[13] Gal Luft and Anne Korin, “Terrorism Goes to Sea,” *Foreign Affairs*, November 2004.

lanes in narrow bodies of water and constrained areas.[14] The International Maritime Bureau (IMB) maintains statistics on pirate attacks and reports a continual rising trend in piracy, with 2007 numbers up 10% (263 attacks) over the previous year and attacks that injured commercial crewmembers up 300% from 2006.[15]

Over 200 years ago, the United States was forced to deploy its fledgling Navy to the Mediterranean to combat piracy and commercial raiding in what is now referred to as the Barbary Wars. This was the first successful attempt of a young republic to protect both its citizens and its economic interests from a ruthless and unconventional enemy overseas in a foreign littoral region. The United States finds itself in a similar situation today, but unlike the pirates of the 19th century who sought quick commercial gain, pirates today consist of maritime terrorists with their own ideological bent and political agenda, in addition to those seeking commercial windfall. However, contrary to popular public misconception, pirates today are not merely “riff-raff” in a rowboat, but rather well-trained and networked fighters aboard high-powered speed boats, equipped with modern technology and weaponry, to include satellite phones and global positioning systems (GPS), as well as automatic weapons.[16]

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[14] Nick Rankin, “British Broadcasting Corporation, “History of Piracy,” http://www.bbc.co.uk/worldservice/documentaries/2008/03/080303_pirates_prog2.shtml, accessed 15 September 2009.

[15] Robert Elliot, “Eastern Inscrutability: Piracy on the High Seas,” *Security Management*, June 2007.

[16] Gal Luft and Anne Korin, “Terrorism Goes to Sea,” *Foreign Affairs*, November 2004.

Considering the significant American dependence on international trade, as well as the dependence on foreign oil and gas shipped via commercial maritime routes, the United States is forced to develop an equally highly technical and networked force to combat piracy and protect commercial interests.

b. Maritime Terrorist Activity

The October 2000 attack on USS COLE, while harbored in the Port of Aden, Yemen, and the subsequent terrorist attacks on September 11, 2001, have increased awareness and discussion on the possibility of maritime terrorist attacks against both commercial and military targets. Closely linked to the aforementioned concept of piracy, maritime terrorist activity differs from piracy in motive and, often times, in final outcome. While piracy actions occur for monetary or political gain, maritime terrorist activity is rooted in the furtherance of ideological philosophy, specifically the use of terror as a means of coercion. In a practical sense, while pirates would hold a ship and crew hostage to receive monetary compensation or political leverage, terrorist action would aim to cripple or destroy the ship and crew in an attempt to spread fear and terror.

After September 11, 2001, the commercial shipping industry increased prevention efforts: verifying the contents of containers and ensuring their security, identifying and screening crewmembers working on maritime platforms, and engaging in ongoing discussions regarding shipping regulations for various chemical and biological weapons. These combined actions led to the creation of the

International Ship and Port Facility Security (ISPS) Code, in an attempt to provide international oversight and partnership against maritime terrorism.[17] However, mere policy proved to be insufficient.

In October 2002, the Limburg, a 300,000 ton tanker, was attacked off the coast of Yemen by a small boat full of explosives, killing one crewmember and spilling almost 100,000 barrels of crude oil into the ocean.[18] This attack highlighted the challenge that maritime terrorists present, as large, lumbering commercial vessels do not possess the speed or agility required to avoid attack from small, agile craft.

Not all maritime terrorism is focused on large, commercial craft. As the attack on USS COLE demonstrated, military vessels are susceptible to terrorist attack, especially while pier side or at anchorage. Additionally, smaller scale commercial shipping is also at risk. In February 2004, Motor Vessel (MV) Superferry 14, a commercial ferry carrying almost 900 passengers, exploded in the waters surrounding the Philippines, directly outside Manila Bay. With 116 deaths and over 300 wounded, it was one of the most gruesome terrorist actions in the Pacific in the new millennium. The radical extremist terrorist organization known as the Abu Sayaff Group (ASG) took responsibility for the attack, citing the attack as "revenge" for the murder of one of their organization's members, as well as a warning against the "ongoing

[17] Graham Ong-Webb, *Piracy, Maritime Terrorism, and Securing the Malacca Straits* (Singapore: Institute of Southeast Asia Studies, 2006), 18.

[18] Ibid.

violence" aimed against them. ASG leader Khadafy Janjalani attempted to further foster the fear and terror of the Filipino public, by saying the "best action of ASG was yet to come."[19]

While differing in tonnage, type, cargo, and flagging, one key commonality between the maritime terrorist attacks on the USS COLE, MV Superferry, and Limburg was their physical geographical location at the time of attack. For all three ships, the attacks occurred not on the open ocean, but rather closer to shore, in the littorals. These regions present a significant security challenge against maritime terrorist threat.

c. Swarm Tactics

The concepts of swarming and swarm tactics are tied closely to both the aforementioned areas of piracy and maritime terrorist activity. Swarming is, in general terms, behavior where a group of individual units work and move as a coordinated whole. As the name alludes, the behavior is seen in the natural world in insects, but has been adopted for tactical military engagement. This military swarming can be further defined as a "scheme of maneuver that involves the convergent attack of five (or more) semiautonomous (or autonomous) units on a targeted force in some particular place. Convergent implies an attack from most of the points on the compass."[20]

[19] Peter Lehr and Rommel Banlaoi, *Violence at Sea: Piracy in the Age of Global Terrorism* (New York: Taylor and Francis Group, 2007), 121.

[20] Sean Edwards, *Swarming on the Battlefield: Past, Present, and Future* (RAND 2000), 2.

Used predominantly in a tactical situation, swarming is an asymmetric technique utilized by a lesser force against a greater force, where the sum of the combined efforts of numerous elements of the lesser force is able to overcome the more capable foe. The key to a successful swarm operation is the continued development and utilization of communication and information networks. To combat this type of tactic, a similarly agile, responsive, and networked collection of platforms must be employed against the adversary in the littoral region. Falling directly in line with the NBW concept, the interconnectedness and robust information sharing capability are vital to successfully combating swarm techniques.

In January 2008, five Iranian Revolutionary Guard (IRG) fast-boats conducted a variation of traditional swarm tactics against three U.S. warships operating in the Straits of Hormuz. The five Iranian vessels maneuvered against the U.S. ships in ways described by a Pentagon official as "careless, reckless, and potentially hostile." Vice Admiral Cosgriff, U.S. Navy Fifth Fleet Commander, deemed the IRG actions as "unduly provocative" and expounded further saying the U.S. ships "received a radio call that was threatening in nature, to the effect that they were closing on our ships and ... the U.S. ships would explode."[21] The IRG has been designated as a weapons proliferator, as well as a supporter of terrorist activity. While no attacks were made against the U.S. warships, the unconventional swarm techniques used by the IRG received

[21] Andrew Gray, "Iranians Threatened U.S. Ships in Hormuz," *Reuters*, 7 January 2008.

international attention and demonstrated the potential risk that existed for ships in the Arabian Gulf and in littoral regions world-wide.

d. Littoral ASW Operations

The last significant littoral threat and challenge we will examine is the subsurface and ASW operations within the littoral. In the context of U.S. joint-force operations, "successful littoral ASW clears the undersea battle-space of hostile submarine influence and permits American and combined forces to maneuver at will to best employ their assets at the time and place of their choosing."[22] The importance of a littoral ASW capability cannot be overstated. It is essential to maintain the capability to protect naval assets, as well as commercial and logistic shipping, from the threat of potential enemy submarines. Maintaining this capability allows the United States to "project power ashore, conduct strategic sealift operations, and control or interdict sea lines of communications (SLOCs) that affect littoral objectives."[23]

ASW techniques, practices, and systems employed in the open ocean are not necessarily successful in the littoral regions. Due to high surface traffic volume, geographical bounding, bathymetric challenges, and relative stealth of subsurface platforms operating in the area, littoral ASW operations require a different approach, from both a tactics and systems standpoint. The littorals

[22] Navy Doctrine Command, "Littoral Antisubmarine Warfare Concept," http://www.fas.org/man/dod-101/sys/ship/docs/aswcncpt.htm, accessed 15 September 2009.

[23] Ibid.

present a complex and acoustically noisy environment that confuses and undermines standard blue-water ASW sensors. As such, successful ASW operations in these areas rely more heavily on non-acoustic sensors to aid in detection and tracking of subsurface targets. According to U.S. Navy doctrine on littoral ASW, "the accelerating rate of technological innovation gives increasing advantages to the navies that most quickly introduce appropriate new technologies into their fleets."[24]

2. Maritime Littoral Platforms

For the purpose of this thesis, we will focus attention on the LCS and the direct implementation of its indigenous ISR assets. While other surface platforms, including frigates, cruisers, and destroyers, are capable of operations within the littorals, it is not their primary designed functionality. Additionally, while the potential exists for UAV assets in conjunction with the LCS, the scope of this thesis will focus on the manned aircraft available due to resource limitation in the field-testing environment. Further discussion of applicability to unmanned assets can be found in Chapter IV, under future recommendations. The focus of the analysis in this thesis is on the sensors employed by the maritime aircraft, but we will first present a baseline understanding of the platforms themselves.

a. LCS

In November 2001, the DoN announced a revised Request for Proposal (RFP) for the future surface

[24] Navy Doctrine Command, "Littoral Antisubmarine Warfare Concept."

combatants program. Re-coined DD(X) from its original DD 21 moniker, this revised request included three platforms, a modified guided missile cruiser and multi-mission destroyer, tentatively named CG(X) and DD(X) respectively, and the LCS.[25] The inclusion of the LCS alongside the CG(X) and DD(X) in the revision marked a tangible mind-shift in planning for twenty-first century naval operations. Only a year prior, Congress was provided a report outlining the Navy's 30-year shipbuilding plan, in which the potential contribution of small combatants in future operations was downplayed and the smallest discussed surface platform was over three times the size of current LCS designs.[26]

After the decision was made to fund the future LCS program on the conceptual level, many questions still abounded as to the direction of the program and requirements for the specific platforms. In July 2002, the Naval War College (NWC) released the results of an 18-month series of workshops and discussions, pulling from their broad knowledge base of indigenous staff and students to develop desirable characteristics and requirements of an ideal littoral surface platform. Their list contained eight main focus areas:

1. be capable of networking with other platforms and sensors;
2. be useful across the spectrum of conflict;

[25] Aykut Kurtman, Evaluation of the Littoral Combat Ship (Monterey: NPS Thesis, 2006).

[26] Robert Work, *Naval Transformation and the Littoral Combat Ship* (Washington D.C.: Center for Strategic and Budgetary Assessments, 2004).

3. be able to contribute to a sustained, forward naval presence;
4. be capable of supporting manned vertical lift aircraft;
5. be capable of operating with reduced manning;
6. have an open architecture and modularity;
7. be capable of controlling manned and unmanned vehicles;
8. have organic self-defense capabilities.[27]

Over the next two years, this list and other requirements for the LCS were refined through a number of studies of current and potential threats, as well as analyses of future military operations in the littoral regions. From these, the U.S. Navy developed finalized requirements for the LCS that addressed the identified capabilities desired and threats in the littorals. The LCS would be a modular ship, capable of supporting mine warfare, ASW, and SUW modules, as primary mission areas.[28] Additionally, LCS would also need to be capable of conducting numerous secondary missions such as ISR, MIO, humanitarian missions, and special operations support. The aim was for a small, agile, flexible, multi-mission capable ship with the ability to operate both independently and within a network of others, to enhance U.S. Naval capability within the littoral regions. Specifically, the 2004 Interface Control Document (ICD) for the LCS stated:

[27] Aykut Kurtman, *Evaluation of the Littoral Combat Ship* (Monterey: NPS Thesis, 2006).

[28] Ibid.

> The LCS platform shall be designed to accommodate multiple reconfigurable modular mission packages to accomplish focused missions via an open and modular design that provides flexibility and ease of upgrade while ensuring rapid and successful installation and integration of the mission packages to the platform. To permit use of a wide range of both present and future mission systems and to permit platform and mission systems to be developed independently, a standard interface in the form of a standard technical architecture must be used. The industry shall design and build the LCS platform, employing an open modular architecture for mission systems based on this standard technical architecture. Separately, mission modules will be developed for the LCS based on this technical architecture. [29]

In May 2004, the U.S. Navy awarded contracts to two competing companies for the initial four ships of the LCS Class. Lockheed Martin Corporation was awarded 46 million dollars to build LCS 1 and LCS 3, while General Dynamics was awarded 78 million dollars to build LCS 2 and LCS 4. The specific design of the LCS platform varied distinctly between the two companies.

The Lockheed Martin design was based on its advanced steel mono-hull and the General Dynamics design was based on a more nontraditional “trimaran” hull. While different in appearance, both designs were to meet the performance requirements as laid out by the Navy. Both designs could achieve sprint speeds of over 40 knots as well as long-range transit distances of over 3,500 miles. The sea frames of each design could accommodate the equipment and crews of the focus mission packages and effectively launch, recover, and control unmanned vehicles

[29] Naval Sea Systems, *Draft interface control document,* 2004.

for extended periods of time in various sea states, though the methods by which each launch and recover aircraft and waterborne craft are different.[30] After the development and initial deployment of these four vessels, the Navy's plan was to determine the optimal characteristics in each design and include those characteristics in the planned 55-ship class. Figures 2 and 3 show the conceptual briefing slide and picture of the LCS 1, while Figures 4 and 5 provide the same for LCS 2.

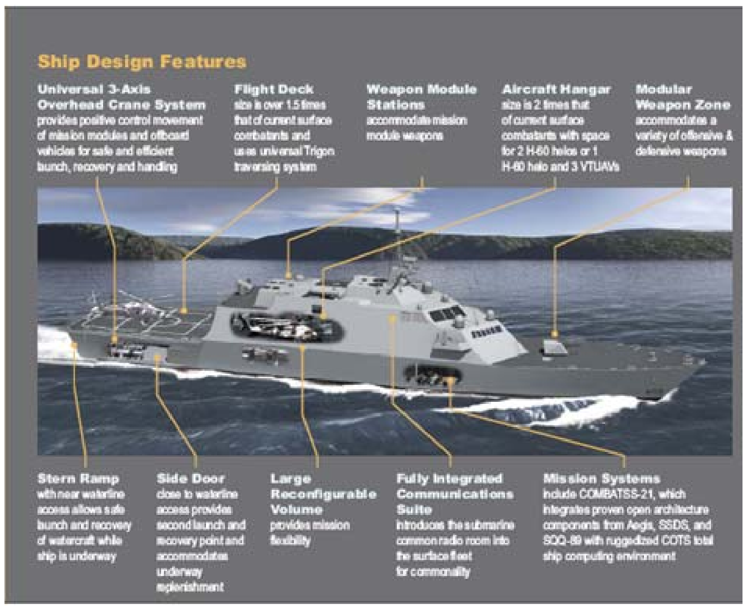

Figure 2. LCS 1 Briefing Slide[31]

[30] GlobalSecurity.Org, "Littoral Combat Ship," http://www.globalsecurity.org/military/systems/ship/lcs.htm, accessed 15 September 2009.

[31] Image Shack Online Media Hosting, "Littoral Combat Ship-1," http://img523.imageshack.us/img523/7409/lcs1fu4.png, accessed 15 September 2009.

Figure 3. LCS 1 at Sea (head on)[32]

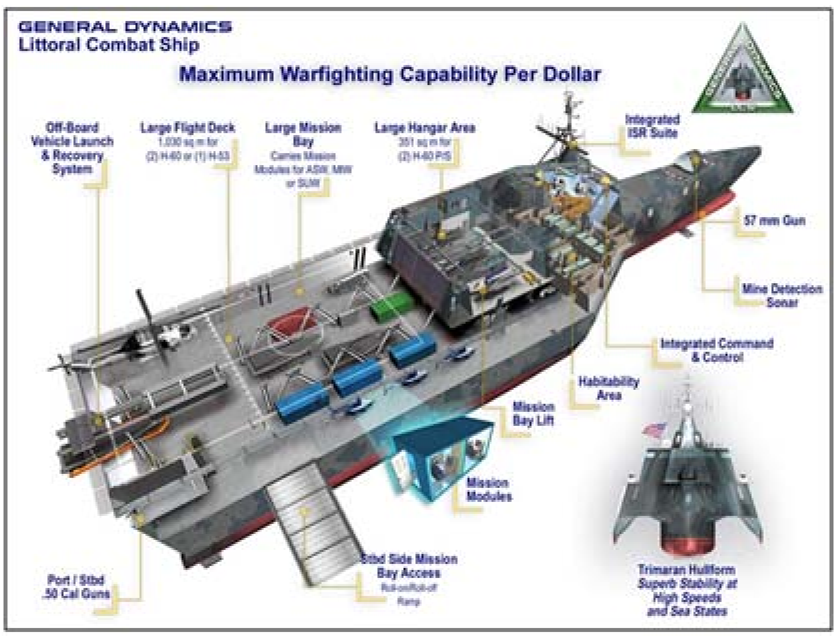

Figure 4. LCS 2 Briefing Slide[33]

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32 New Wars, Word Press.com, "LCS Littoral Combat Ship-1," http://newwars.files.wordpress.com/2008/08/lcs1.jpg, accessed 15 September 2009.

33 Defense Industry Daily, "General Dynamics Littoral Combat Ship," http://www.defenseindustrydaily.com, accessed 15 September 2009.

Figure 5. LCS 2 (head-on)[34]

Since the awarding of the initial contracts, the entire LCS program has seen a great deal of criticism. In June 2005, the Lockheed Martin LCS 1 was named FREEDOM and her keel was laid in Marinette, Wisconsin. In January 2006, the General Dynamics LCS 2 was named INDEPENDENCE and her keel was laid in Mobile, Alabama. However, in April 2007, the Navy canceled the contract with Lockheed Martin for LCS 3 and followed suit seven months later with General Dynamics, cancelling the contract for LCS 4.[35] [36]

Though the Navy cited significant cost overruns as the driving factor behind the contract cancellations, the need for the LCS did not wane. In public comments following the contract cancellations, the Secretary of the

[34] Strategy Page, "Littoral Combat Ship-2," http://www.strategypage.com/military_photos/2008120422651.aspx?comments=Y, accessed 15 September 2009.

[35] Rene Merle, "Navy Cancels Lockheed Ship Deal," *Washington Post,* 13 April 2007.

[36] U.S. Navy Press Release No. 1269-07, "Navy Terminates Littoral Combat Ship (LCS 4) Contract," 1 November 2007.

Navy (SECNAV), the Honorable Donald Winter, stated, “LCS continues to be a critical war-fighting requirement for our Navy to maintain dominance in the littorals and strategic choke points around the world.”[37] The Chief of Naval Operations (CNO), Admiral Gary Roughead was in the same accord, stating, “I am absolutely committed to the Littoral Combat Ship. We need this ship. It is very important that our acquisition efforts produce the right littoral combat ship capability to the fleet at the right cost.”[38]

In April 2008, the Navy re-engaged with both General Dynamics and Lockheed Martin, requesting new proposals for future LCS platforms.[39] The Navy agreed to a new contract for LCS 3 with Lockheed Martin in March 2009 and for LCS 4 with General Dynamics in May 2009.[40]

In the months following this announcement, there have been various other public statements from congressional oversight committees and defense analysts regarding contract caps, cost over-runs, and even some critics calling to cancel the program all together. But, for the foreseeable future, the LCS development program will continue, with the Secretary of Defense (SECDEF) reiterating that the Fiscal Year (FY) 2010 budget will include three LCS platforms with the plan for up to 55

[37] U.S. Navy Press Release No. 1269-07, “Navy Terminates Littoral Combat Ship (LCS 4) Contract,” 1 November 2007.

[38] Ibid.

[39] David Sharp, “Navy Restarting Contest for Halted Shipbuilding Program,” *Washington Post,* 03 April 2008.

[40] National Briefin, “Lockheed Gets Second Ship Deal,” *Washington Post,* 24 March 2009.

littoral platforms in the future.[41] This continued expressed commitment to the LCS program highlights the DON and DoD leadership's emphasis on flexible, multi-mission capable platforms.

Both the Lockheed Martin and General Dynamics versions of the LCS platform are equipped with both a helicopter flight deck and hangar, capable of storing both manned rotary wing aircraft and unmanned aerial vehicles. The primary manned maritime aircraft for use onboard the LCS will be variants of the SH-60 Seahawk.

b. SH-60 Seahawk

The Sikorsky SH-60 Seahawk is a twin turbo-shaft engine, multi-mission helicopter in current use by the U.S. Navy. The Navy selected the Seahawk to replace the aging SH-2 Sea Sprite in 1978 and took possession of the first aircraft in 1983. As continued improvements were made to the Navy's Light Airborne Multi-Purpose System (LAMPS) avionics suite, the Sea Sprite did not possess the endurance or lift capability to support the required equipment of LAMPS Mk II and III.[42] The Seahawk is able to deploy on any air-capable surface ship, including frigates, destroyers, cruisers, aircraft carriers, and amphibious ships, as well as the new LCS class. The Seahawk has traditionally existed in four main designations, SH-60B, SH-60F, MH-60S, and HH-60H, encompassing various specific

[41] Secretary of Defense, "DoD News Briefing With Secretary Gates," http://www.defenselink.mil/transcripts/transcript.aspx?transcriptid=4396, accessed 15 September 2009.

[42] Ray Leoni, *Black Hawk: The Story of a World Class Helicopter* (American Institute of Aeronautics and Astronautics, 2007).

mission areas, including ASW, SUW, SAR, CSAR, transport, logistics, vertical replenishment (VERTREP), and medical evacuation (MEDEVAC).[43]

The SH-60B LAMPS Mk III variant is primarily deployed aboard frigates, destroyers, and cruisers, and primarily provides an ASW and SUW capability. The SH-60F LAMPS Mk III variant is the aircraft carrier based version of the SH-60B, having replaced the SH-3 Sea King as the Carrier Strike Group's (CSG) primary ASW and SUW asset, though other variants can also deploy and operate from an aircraft carrier as well.

While the SH-60B is equipped with a towed Magnetic Anomaly Detector (MAD) and sonabouy capability, the SH-60F variant is equipped with the AQS-13F dipping sonar, improving its acoustic ASW capability compared to the SH-60B.[44] The U.S. Navy is currently in the midst of converting all SH-60Bs and then SH-60Fs into a combined, multi-mission SH-60R platform. The new SH-60R variant provides:

- Upgraded mission and flight displays
- Improved advanced flight control computer
- RADAR upgrade
- Electronic Support Measures (ESM) upgrade
- Improved integrated self defense
- Dipping sonar upgrade

43 U.S. Navy Fact File, "SH-60 Seahawk Helicopter," http://www.navy.mil/navydata/fact_display.asp?cid=1200&tid=500&ct=1, accessed 15 September 2009.

44 Paul Eden, *Encyclopedia of Modern Military Aircraft/Sikorsky H-60 Sea Hawk* (Amber Books, 2004), 431.

The SH-60R will have the ability to operate from all helicopter capable surface platforms and will be the SH-60 variant primarily used on LCS.[45] Additionally, the SH-60R will incorporate non-mission specific avionics within its new "glass-cockpit" to facilitate the multi-mission capability of the airframe. A "glass-cockpit" features electronic instrument displays driven by a flight management system (FMS), where traditional cockpit design uses numerous mechanical gauges to display information. This simplifies aircraft operation and navigation, allowing pilots and aircrewmen to focus predominantly on pertinent information. Specifically, it will allow the same pilot to shift from an ASW mission to a SUW or cargo transport mission in the same airframe with the same cockpit configuration. The extended platform and mission flexibility afforded by this cockpit reconfiguration aligns under the broad mission set needed for operations within the littorals.

Two other variants of the SH-60 are the MM-60S and the HH-60H. The MM-60S replaces the H-46 within the naval aviation inventory and will serve primarily as a VERTREP, logistics, and transport platform, with a secondary SAR mission. The HH-60H variant is specifically figured for Combat SAR (CSAR) and navy special warfare (NSW) support. For the scope of this thesis, we will limit focus to the new SH-60R variant, as it will comprise the majority of manned maritime rotary winged aircraft used in littoral operations.

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[45] Lockheed Martin, "MH-60 *Helicopter* Departs Lockheed Martin to Complete First Operational Navy Squadron," Lockheed Martin Press Release, http://www.lockheedmartin.com/news/press_releases/2008/0730si-mh-60r.html, accessed 15 September 2009.

Traditionally, SH-60B variant was deployed on the smaller surface combatants with the SH-60F and MM-60S conducting operations from the aircraft carrier. The SH-60 footprint in a Navy CSG was two SH-60Bs onboard a cruiser, two SH-60Bs on a destroyer, one SH-60B on a frigate, and four SH-60Fs and four HH-60Hs onboard the aircraft carrier. While the number of ships within the CSG is not static and can change, a 14 SH-60 variant presence was common across all surface platforms within the CSG. As the SH-60B and SH-60F are replaced by the multi-mission SH-60R, the new SH-60 footprint with the CSG will be comprised of four MH-60R and eight MM-60S variants onboard the aircraft carrier, with two SH-60R variants onboard the cruiser and destroyer respectively and one SH-60R variant on the frigate. This new planned deployment will increase the total number of SH-60 variants in the strike group and will provide nine multi-mission capable helicopters for the CSG commander.[46] The LCS has the capability to deploy with up to two SH-60 variants. Figures 6 and 7 show a picture and schematic drawing of the SH-60 Seahawk.

[46] Email Exchange with Peter Yu, Seahawk Wing Training Instructor, HSM Weapons School Pacific, NAS North Island, CA, August 2009.

Figure 6. SH-60 Seahawk in Flight[47]

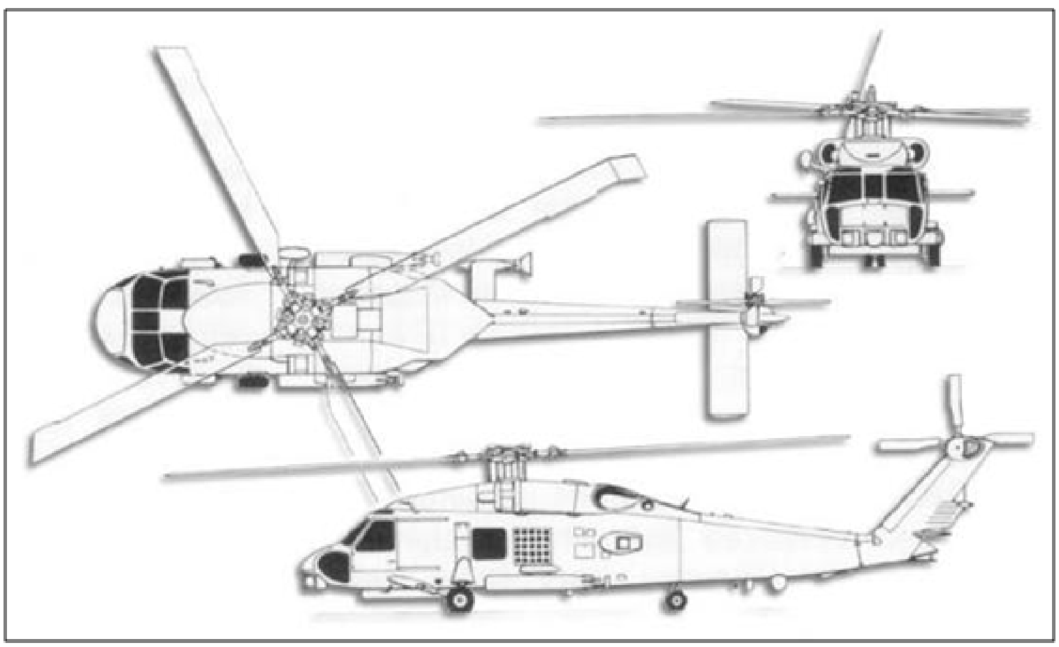

Figure 7. Schematic Drawing of SH-60 Seahawk[48]

47 Aerospace Web.org, “SH-60 Sea Hawk,” www.aerospaceweb.org, accessed 15 September 2009.

C. MARITIME ISR

According to DoD Joint Publication (JP) 1-02, ISR is an activity that synchronizes and integrates the planning and operation of sensors and assets, as well as the processing, exploitation, and dissemination of information in direct support of current and future operations.[49] It refers to the sets of collection and processing systems and associated operations involved in acquiring and analyzing information about a given target.

The JP further defines the three ISR components individually:

- Intelligence—the product resulting from the collection, processing, integration, evaluation, analysis, and interpretation of available information concerning foreign nations, hostile or potentially hostile forces or elements, or areas of actual or potential operations.
- Surveillance—the systematic observation of aerospace, surface, or subsurface areas, places, persons, or things, by visual, aural, electronic, photographic, or other means.
- Reconnaissance—a mission undertaken to obtain, by visual observation or other detection methods, information about the activities and resources of an enemy or adversary.[50]

Intelligence is broader and more encompassing, while surveillance refers to systematic observation of a targeted area or group over a short or extended time, and

[48] Aerospace Web.org, "3-view schematic," www.aerospaceweb.org, accessed 15 September 2009.

[49] U.S. Department of Defense Joint Publication 1-02, *Department of Defense Dictionary of Military and Associated Terms*, 12 April 2001.

[50] Ibid.

reconnaissance refers to an effort or a mission to acquire information about a target and can mean a one-time endeavor.

The Congressional Research Service (CRS) recently compiled information on DoD ISR operations, providing a very succinct overview of ISR operations. They surmised:

> ISR functions are principal elements of U.S. defense capabilities, and include a wide variety of systems for acquiring and processing information needed by national security decision-makers and military commanders. ISR systems range in size from hand-held devices to orbiting satellites. Some collect basic information for a wide range of analytical products; others are designed to acquire data for specific weapons systems. Some are 'national' systems intended primarily to collect information of interest to Washington-area agencies; others are 'tactical' systems intended to support military commanders on the battlefield.[51]

For the scope of this thesis, we will focus on indigenous Maritime ISR (MISR) operations. As the name indicates, MISR is ISR operations in the maritime environment. Indigenous MISR refers to those ISR operations launched from a maritime platform in support of that platform's operations, or indigenous to the platform. Specifically, we are evaluating LCS-based, SH-60 variant, rotary-wind aircraft outfitted with various sensor packages conducting indigenous maritime ISR in the littorals. We will first examine the MISR process as a singular system,

[51] Richard Best, "Intelligence, Surveillance, and Reconnaissance Programs: Issues for Congress," *Congressional Research Service,* 22 February 2005.

then focus on the system-of-systems that make-up the process, and then look at the indigenous assets conducting MISR.

1. Intelligence Cycle and ISR Process

Maritime ISR is a hybrid combination of the traditional Intelligence Cycle (IC) and traditional ISR process. The IC is defined as "the process by which information is converted into intelligence and made available to users."[52] IC methodology consists of six interrelated operations: planning and direction, collection, processing and exploitation, analysis and production, dissemination and integration, and evaluation and feedback. Figure 8 graphically depicts the IC, with return "evaluation arrows" representing the process evaluation that occurs after product production. The product created from the IC is evaluated, and either deemed satisfactory (thus staying on the outside circle), or it is determined that either a new plan/task or further collection is needed, and the cycle returns back to revisit those specific areas in the IC process.

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[52] U.S. Department of Defense Joint Publication 1-02, *Department of Defense Dictionary of Military and Associated Terms*, 12 April 2001.

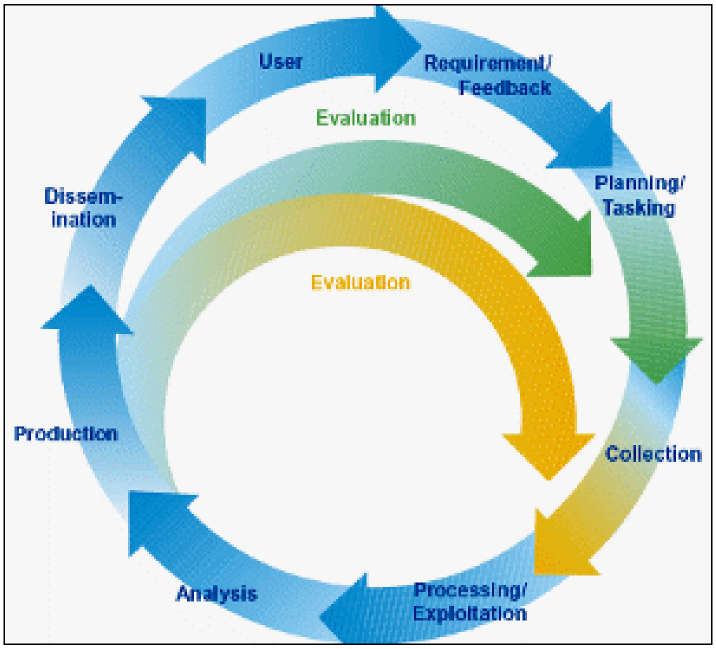

Figure 8. Intelligence Process Cycle[53]

Figure 8 shows the ISR doctrinal methodology (IDM) as compared to the IC methodology. IDM consists of nine interrelated operations: commander's guidance, user's requirements, plan, task/re-task, collect, analyze, disseminate, evaluate, and apply. Like the IC methodology, there is a continual feedback arrow, allow refining, redefinition, and re-tasking throughout the ISR operation.

53 Global Security.Org, "The Intelligence Process," www.globalsecurity.org, accessed 15 September 2009.

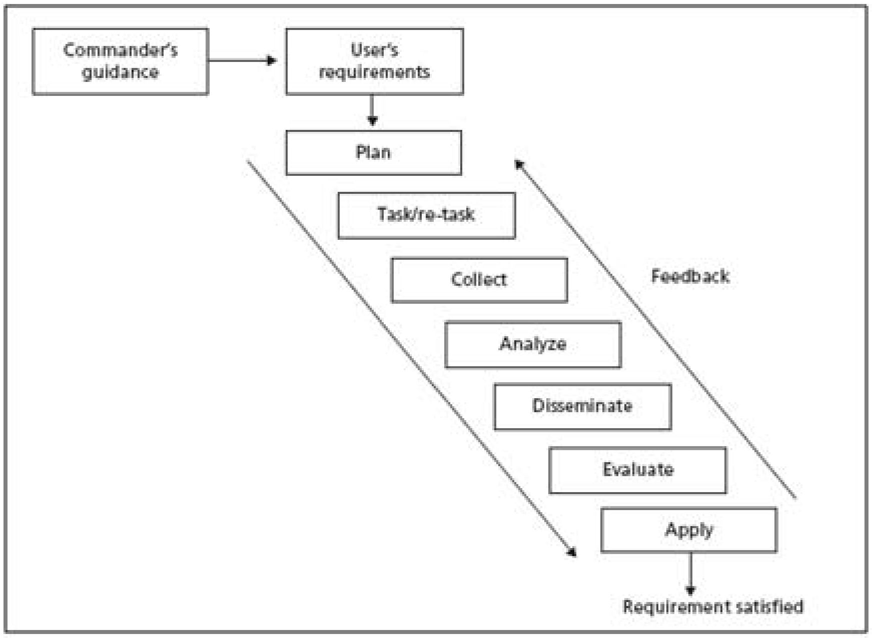

Figure 9. ISR Doctrinal Methodology[54]

2. Maritime ISR Methodology

By examining each individual operation of the IDM in conjunction with the components of the IC, we are able to determine the specific operations that are part of indigenous maritime ISR operations.

IDM components of Commander's Guidance and User's Requirements are the foundation of an ISR operation and are a precursor to entering the circle on the IC model (Figure 9). In this stage, the actual requirement is determined based on threat, operations, or intelligence need (IN). These requirements are prioritized based on various aspects, to include timeliness, current situation, and relevancy.

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[54] Air Force Doctrine Document 2-9, Intelligence Surveillance and Reconnaissance Operations, 17 July 2007.

In the planning and task/re-task phases, available assets to conduct MISR operations are vetted against the requirements determined in the previous stage. Working from the requirement priority list, assets are allocated and tasked to the various requirements. These first four stages are pre-cursors to the MISR operation itself; in the case of this thesis, that is synonymous with launching the SH-60 variant aircraft.

Actual MISR operations begin with the collection phase, which actually consists of the subcomponents of access, detection, and collection. Access refers to the ISR asset or sensor being positioned in the physical proximity or required location to satisfy the given requirement. Access is impacted by a variety of elements, to include the operating environment and ISR platform operating limitations.

Once it has gained access, the next subcomponent of collection is detection. Detection refers to the MISR asset's ability to locate and detect the desired target. Challenges in detection lay with the capabilities of a MISR sensor in conjunction with the difficulties presented by the desired target. For instance, a periscope of a subsurface target in a high-level sea state is relatively difficult to locate, thus, making the detection phase more complicated. Conversely, a large deck surface contact operating in a low sea state is an easier target to locate, thus an easier detection.

Actual collection follows detection and is the recording and observation of the given target of interest by the sensor. In the case of an EO/IR sensor, this is the

photographic or video recording of the target of interest. In the case of other sensors, this could be the recording of RADAR, acoustic signatures, or various other target parameters.

After the successful collection of a signal or image, the next stage in the MISR process is analysis. This stage involves human analytical capabilities as well as automated computer analysis, where the collected information is evaluated and inspected to determine usable value and what significance the information provides.

From this analysis, a report is produced. These reports take various forms, from the formal tactical report (TACREP) and product report mechanisms, to more informal methods of tippers, emails, and data transfers. These reports are then disseminated to various customers and users. The customers then evaluate the information in the reports and apply them to their current needs.

Throughout the MISR cycle, there is a continual evaluation and feedback mechanism. This mechanism allows for an ongoing process of examination of the different stages of the maritime ISR cycle, looking at the specific requirements of each stage and determining if they are completed satisfactorily. If it is determined that there are discrepancies, failures, needed re-tasking(s), or refocusing required at any step within the cycle, the cycle can revert back to a previous stage to ensure requirements are successfully being met.

MISR operations are conducted in direct support of various maritime operations, to include ASW, SUW, MIO, and SAR, and Mine Countermeasures (MCM). Additionally,

maritime ISR platforms can be utilized in a non-traditional capacity ashore, supporting combat SAR (CSAR), overland SAR, counter canopy and concealment operations (CCC), illicit crop detection (ICD), and CIED operations.

3. Indigenous Maritime ISR Technology and Systems

We have previously examined the various platforms employed in MISR operations, looking closely at the LCS and SH-60 Seahawk. In this section, we will focus on the various technologies and specific sensors that these platforms employ conducting MISR operations. For the scope of this thesis, we are focused on the EO/IR capabilities employed by the SH-60 variant. SONAR and RADAR capabilities of the SH-60 are crucial elements in the maritime ISR process, but they are a static capability creating a consistent baseline to cue the EO/IR assets we will discuss in the following sections. As such, they are not a focus area in this thesis. We touched on the basics of EO/IR sensors in Chapter I and will now look further at various advanced technologies and the systems that employ them.

a. Multispectral Imagery

Multispectral Imaging (MSI) is a technology that captures light from frequencies beyond the visible light range, into both the IR and ultraviolet (UV) range. Going beyond the human eye capabilities of red, green, and blue, MSI is a combination of multiple digital images from multiple cameras/devices capturing images in various portions of the visible and IR spectra. These MSI sensors look for the unique fingerprint or spectral signature that

an object leaves across the EM spectrum. This spectral signature is what enables positive identification of the imaged object detected by the MSI sensors.

MSI is steadily growing in popularity within DoD as a digital means for mission planning, thermal signature detection, and terrain analysis, as the ability to record spectral reflectance in different portions of the EM spectrum has been found useful in a number of various applications.[55]

MSI focuses on both the visible light and IR portion of the EM spectrum. The IR portion of the EM spectrum covers the range from 300 GHz to 400 THz and can further be divided into three sub-categories: Far-IR, Mid-IR, and Short Wave/Near-IR. [56]

Above the IR frequencies in the EM spectrum is the visible light range. As the name indicates, this is the portion of the EM spectrum detectable by the human eye and is broken into subsets by color bands. A rainbow, therefore, is composed of the visible light portion of the EM spectrum. Theoretically, though undetectable to the human eye, IR frequencies fall outside the red portion of the rainbow, while UV radiation exists beyond the violet end. Figure 10 graphically displays the ranges and associated frequencies of the EM spectrum, to include the visible light, IR, and UV ranges.

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[55] Air University, "Space Primer, Ch 12, Multispectral Imaging," http://space.au.af.mil/primer/index.htm, accessed 15 September 2009.

[56] Ibid.

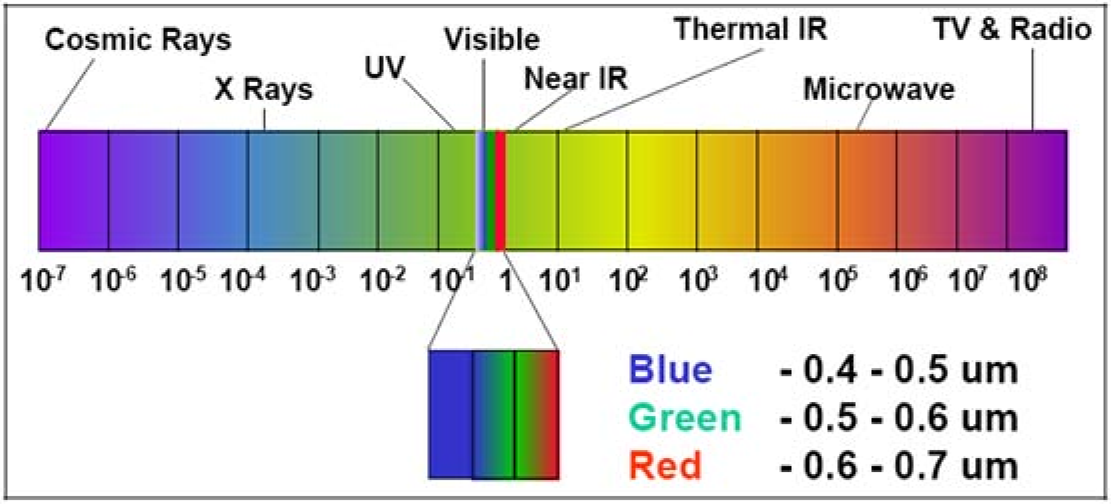

Figure 10. EM Frequency Spectrum[57]

When considering an MSI system, there are designated sensors for each individual band of the previously discussed visible light and IR range of the EM spectrum. Each individual band has different detection capabilities and associated target sets. The various MSI EM bands are outlined below and graphically depicted in Figure 11.

- Band 1- Blue visible light band; used for soil, vegetation and coastal water mapping as well as atmospheric and deep water imaging.

- Band 2- Green visible light band; used for depicting green reflectance of vegetation as well as deep water structural imaging.

[57] South Carolina Department of Natural Resources, "Electromagnetic Spectrum," http://www.dnr.sc.gov/ael/personals/pjpb/lecture/spectrum.gif, accessed 15 September 2009.

- Band 3- Red visible light band; used for differentiating vegetation as well as imaging of man-made objects and shallow water imaging.

- Band 4- Near-IR band; used for vegetation and biomass surveys.

- Band 5- Short Wave IR band; used for discriminating between liquid densities (i.e. oil on water) and various vegetation types, as well as detecting moisture content.

- Band 6- Mid-IR band; used for sensing vegetation moisture, snow/cloud reflectance differences, and soil variations.

- Band 7- Long Wave-IR band, also called Thermal IR; used for thermal mapping, including thermal differences in water and night imaging; utilizes emitted radiation vice reflected radiation.[58]

[58] Air University, “Space Primer, Ch 12, Multispectral Imaging,” http://space.au.af.mil/primer/index.htm, accessed 15 September 2009.

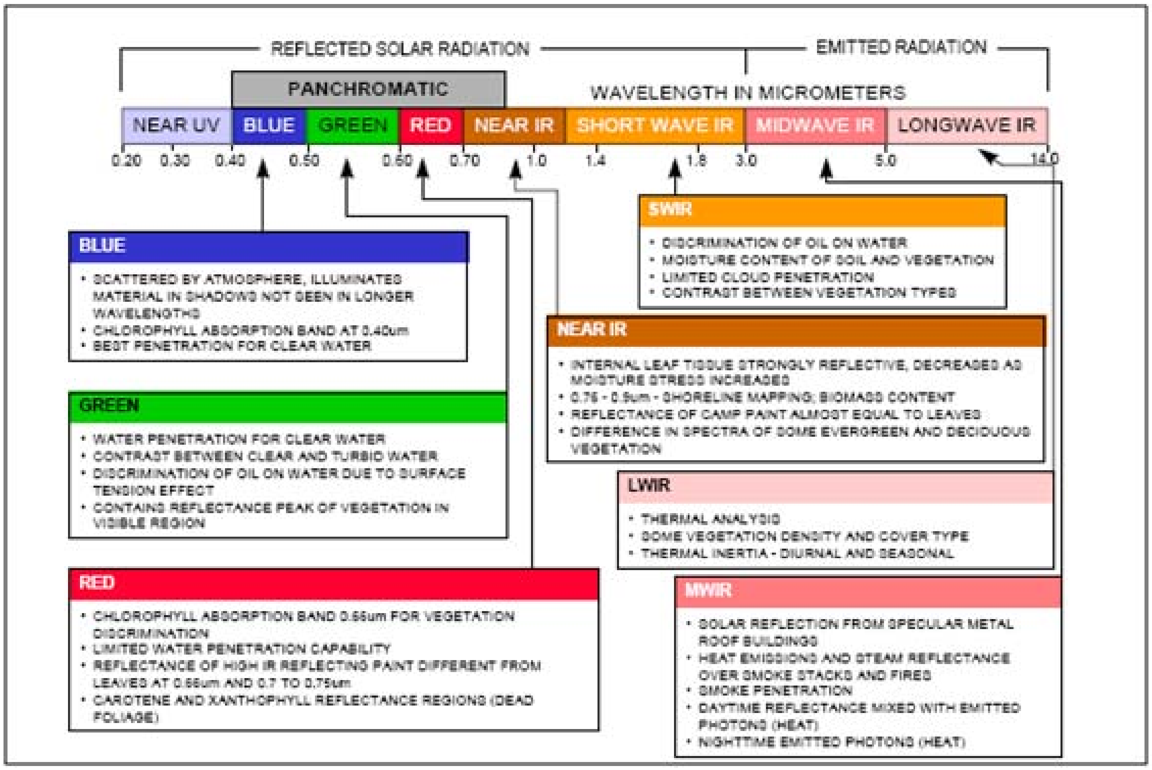

Figure 11. MSI EM Frequency Bands[59]

b. *Hyperspectral Imagery*

Like MSI above, Hyperspectral Imagery (HSI) also collects and processes information across the EM spectrum, from the visible light ranges to the IR and UV range. HSI individually collects information as a set of images in its specified spectral band and then combines them to form a three dimensional (3D) hyperspectral cube for further processing and analysis.[60]

MSI and HSI are similar practices of spectral analysis, with two significant differences. First, is the

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[59] Air University, "Space Primer, Ch 12, Multispectral Imaging," http://space.au.af.mil/primer/index.htm, accessed 15 September 2009.

[60] Nahum Gat, "Directions in Environmental Spectroscopy Industrial Trends, Hyperspectral Imaging," *Spectroscopy Showcase*, March 1999.

number of spectral bands utilized. MSI data contains ten to hundreds of bands, while HSI data contains hundreds to thousands of bands, a significant increase. As a result, HSI products provide increased resolution and accuracy, as well as further detail not always detected by MSI. Second, is in the methodology of data collection. MSI data consists of a set of optimally selected non-contiguous bands, while HSI data consists of a set of contiguous bands. Graphical representation of the MSI and HSI differences are graphically depicted in Figure 12. It is clear to see the difference in number of spectral bands utilized, as well as the effect of HSI utilizing contiguous bands.

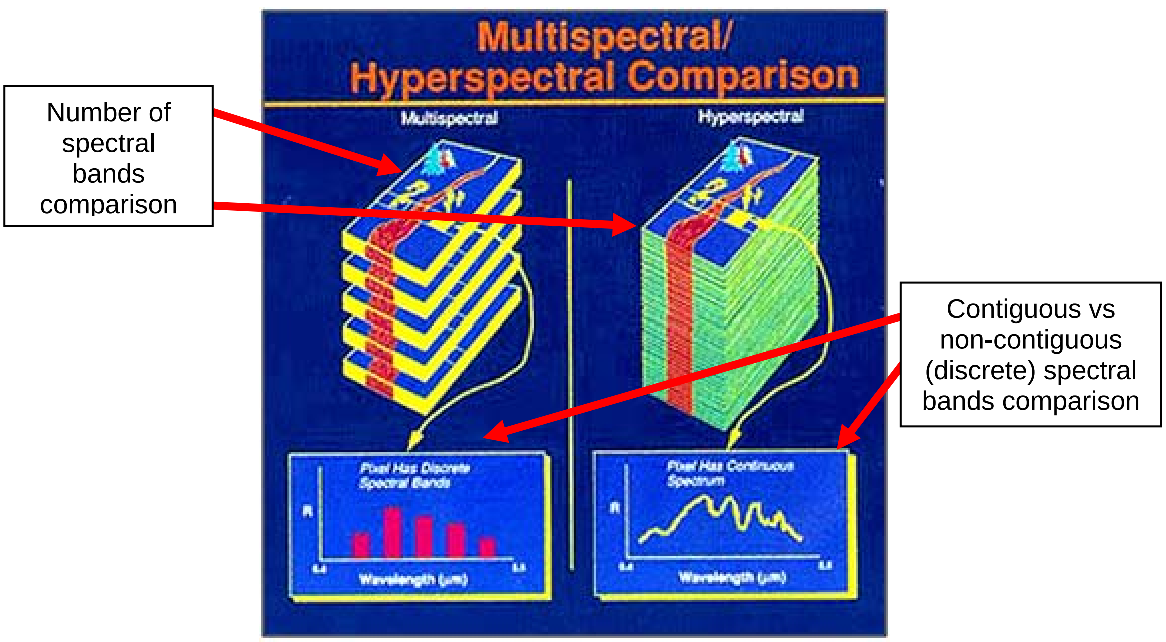

Figure 12. MSI/HSI Comparison[61]

[61] Federation of American Scientists, "Remote Sensing Tutorial," www.fas.org, accessed 15 September 2009.

c. EO Passive ASW System (EPAS)

EPAS program specifications and information will be limited at this classification level. This thesis is intentionally unclassified in its entirety, therefore only the basics of EPAS will be discussed and an EPAS overview provided in generalities.

EPAS is a research and development (R&D), passive EO camera system installed within a 16-inch turret, used for maritime surface and subsurface imaging. At the core of EPAS technology are four integrated non-acoustical detection technologies. This core consists of a 12-channel visible multi-spectral imager, a three-channel low-level-light spectral detector, a three-channel low-light zoom capable camera, and a mid-wave IR detector.[62] Ultimately, 12 individual cameras are utilized to collect the multi-spectral data.

EPAS technology can be installed on any airborne platform with a 16-inch turret mount and is currently employed on the P-3 Orion maritime patrol aircraft (MPA). Other potential future platforms for include the SH-60 Seahawks, the P-8A follow-on multi-mission MPA, as well as UAVs. EPAS technology improvement research includes examining ways to include polarization capabilities and improved processing algorithms to improve detection capabilities in sea foam and higher sea-states, as well as

[62] Navy SBIR FY2006.1, "Technology Development for a Multi-Mission Passive Anti-Submarine Warfare (ASW) Turret Capability," http://www.navysbir.com/06_1/93.htm, accessed 15 September 2009.

continued research to improve overall system performance while reducing both the size and weight dimensions of the system.[63]

d. AAS-44 Forward Looking Infra Red Turret (FLIR)

The AAS-44 FLIR turret has been utilized onboard the SH-60 since 1997. The system is a second generation FLIR with three fields of view: image enhancing local-area processing; electronic zoom, dual-mode automatic video tracker; and a digital video interface for aircraft-to-ship data-link. The sensor, coupled with a laser range-finder (LRF) and laser designator (LD), is installed on a six-axis gimbals in a nose-mounted turret aboard the airframe.[64] Developed by Raytheon, the AAS-44 provides both general optical surveillance capability, as well as providing line-of-sight targeting and illumination capability for Hellfire and laser-guided bombs. Figure 13 shows a close-up view of the AAS-44 FLIR turret and Figure 14 shows the SH-60 with the AAS-44 installed.

[63] 63Navy SBIR FY2006.1, "Technology Development for a Multi-Mission Passive Anti-Submarine Warfare (ASW) Turret Capability," http://www.navysbir.com/06_1/93.htm, accessed 15 September 2009.

[64] Janes International Defence Review, "Naval Helicopter Sensors and Weapons Systems, September 2001.

Figure 13. AAS-44 FLIR Turret[65]

Figure 14. AAS-44 FLIR Turret onboard SH-60 Seahawk[66]

The follow-on EO system to the AAS-44 is the AAS-52, which increases the fields of view, adds color and low-light television cameras, and includes a three-mode auto-tracker. The Multispectral Targeting System Bravo (MTS-B),

[65]Raytheon, "AAS-44 Data Sheet," www.raytheon.com, accessed 15 September 2009.

[66] GUNCOPTER.COM, "SH-60 B/F with FLIR," www.guncopter.com/sh-60-sea-hawk, accessed 15 September 2009.

a modified FLIR turret from the AAS-52 family, has been selected has been selected for the AAS-44 follow-on system onboard the SH-60 variants.[67]

e. MTS-B

Raytheon’s MTS-B is a multi-use EO/IR system designated as the follow-on system to the AAS-44 FLIR. Like its predecessor, MTS-B provides both general optical surveillance capability, as well as providing line-of-sight laser targeting, automatic video tracking (AVT), and laser illumination. However, the MTS-B has an improved detection range, both in physical distance and capability across the IR spectrum, as well as improved image resolution[68]. Specifically, MTS-B incorporates seven EO and IR cameras, ranging from wide to ultra-narrow view with a 2:1 and 4:1 electronic zoom capability in IR and television mode respectively. Additional available options include EO television sensors, intensified television sensors, illuminator, eye safe rangefinder, and spot-tracker. [69] Figure 15 shows the MTS-B system.

[67] Norman Friedman, *The Naval Institute Guide to World Naval Weapons Systems* (Naval Institute Press, 2006), 206.

[68] Email Exchange with Peter Yu, Seahawk Wing Training Instructor, HSM Weapons School Pacific, NAS North Island, CA, August 2009.

[69] Tony Costales, “Multi-spectral Targeting System,” *Raytheon*, 2008.

Figure 15. MTS-B FLIR System[70]

f. MX-15D Wescam Turret

L-3 Wescam produces a variety of EO/IR turrets employed internationally onboard multiple private and government manned and unmanned aircraft. The baseline EO/IR turret employed with the JMMES system, the L-3 Wescam MX-15D, maintains the capability for multiple configuration and camera/sensor installation to meet custom needs of various customers. Specifically, the MX-15D has the flexibility to install up to five of the following:

- Color daylight camera with zoom lens
- Mono-daylight camera with spotter lens
- IR camera with high level magnification and zoom capability
- LD / LRF capability
- Laser illuminator[71]

[70] Raytheon, "MTS-B Data Sheet," www.raytheon.com, accessed 15 September 2009.

System design and specific camera inclusion for JMMES system optimization will be discussed further in the JMMES section. Figure 16 shows the L-3 Wescam MX-15D turret.

Figure 16. L-3 Wescam MX-15 Turret[72]

g. JMMES EO/IR System

JMMES is a tactical EO/IR sensor suite that simultaneously operates multiple EO/IR sensors while processing imagery using mission specified algorithms. JMMES is capable of performing multiple missions through software modifications that fully employ the baseline standard EPAS sensor suite. The JMMES system consists of a collection of EO/IR cameras mounted in a 15-inch Wescam MX-15-D turret, a JMMES system processor, a separately mounted MAD sensor, and a system operator workstation. For our

[71] Wescam, "Wescam MX-15 Family Products," http://www.wescam.com/products/products_services_1.asp, accessed 15 September 2009.

[72] Wescam, "Wescam MX-15 Family Products."

testing purposes and for the scope of this thesis, the JMMES system utilized was not equipped with a MAD sensor and the operator workstation was onboard the aircraft. Future possible capabilities include utilizing a data link from the JMMES turret and processor onboard the aircraft to an operator workstation on the ground.[73] Figure 17 shows the various individual components of the JMMES system.

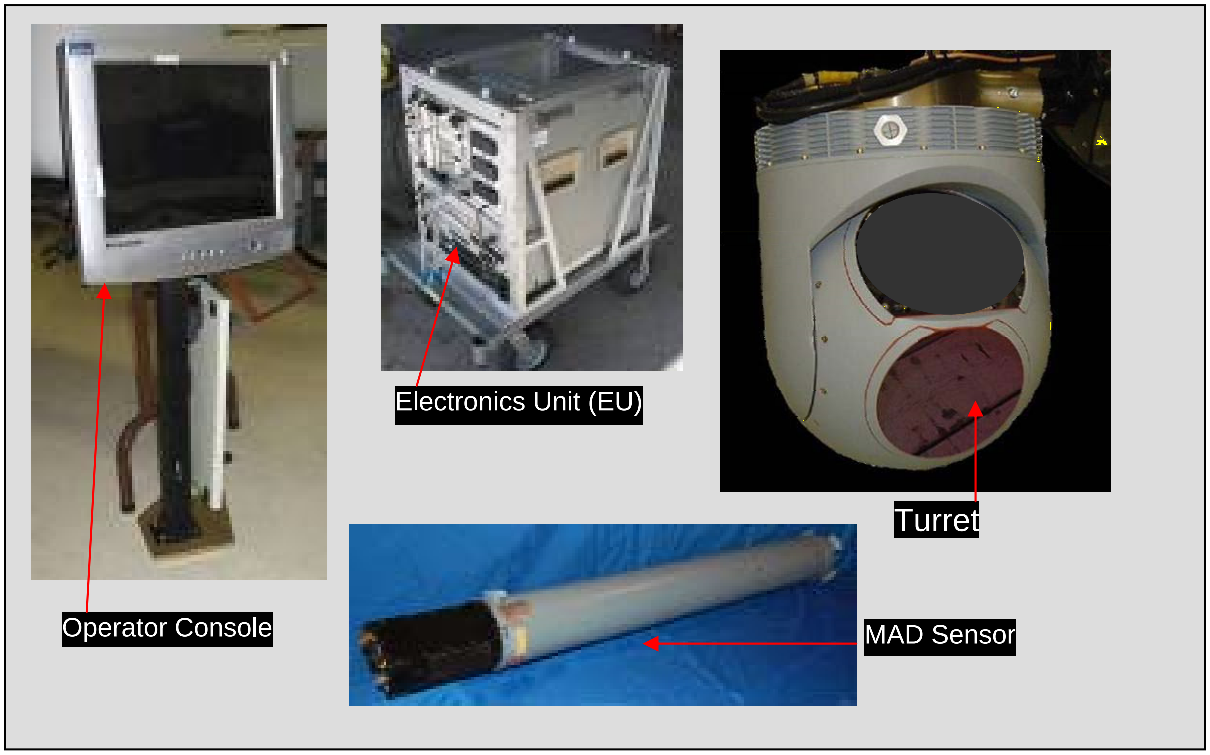

Figure 17. JMMES System Components[74]

The 15-inch Wescam turret houses six different EO/IR sensors as part of the JMMES system. Specifically, these sensors include an EO Wide field of view (EOW), EO medium field of view (EOM), EO narrow field of view (EON),

[73] JMMES JCTD Concept of Employment, 1 December 2007.

[74] Ibid.

Mid-wave IR (MWIR) with four fields of view (narrow, short-wave, medium, long-wave), a bioluminescence EOW low level light sensor, and LD / LRF. Figure 18 shows a graphical display of the EO spectrum and where the various JMMES system sensor components reside.[75]

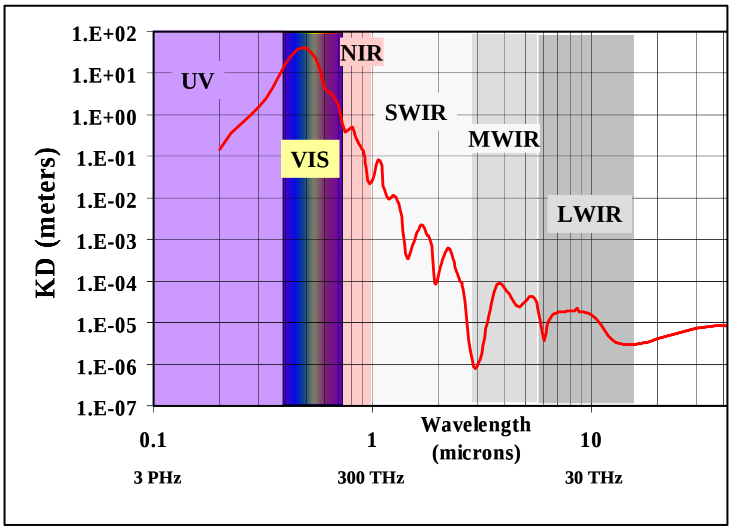

Figure 18. EM Spectrum JMMES Sensor Allocation[76]

Within the JMMES Concept of Employment (COE) document, the specific sensors housed within the turret are discussed in extensive detail. A summary of the sensor discussion is included in the following paragraphs.

The MWIR sensor is a passive broadband sensor that provides the capability to detect objects emitting EM radiation within the IR spectrum. The most easily detectable targets are those considered "hot targets," such as a combustion engine, exhaust, or other targets giving off substantial amounts of heat. Landmines that store daytime heat from the sun are visible to the MWIR sensor as

[75] JMMES JCTD Concept of Employment, 1 December 2007.

[76] Ibid.

the surrounding air and ground cools faster than the mine. The MWIR sensor can also detect objects that are cooler in temperature than the surrounding area, in a practice known as "thermal inertia." While they do give off heat, human targets are more readily detected in the LWIR wavelengths.[77]

The JMMES EOW sensor is a passive 12-band MSI sensor that detects the reflectance of ambient light from a target in the visible spectrum. These MSI sensors are used to detect both land-based and maritime. The EOW MSI sensor is able to penetrate seawater to detect submerged targets, as well as discern and separate sea clutter on the surface.[78]

The JMMES EOM sensor is a passive four-band MSI sensor, operating in the VNIR spectrum and reliant on the detection of reflected ambient light from a target. It is optimally used for the detection of landmines, ocean mines in water depths up to 40 feet. The EOM sensor has a much smaller field of view than the EOW sensor, but since the four EOM bands are inclusive in the set of 12 bands from the EOW sensor, the EOM sensor can provide a zoom-like functionality across those four specific bands for objects detected in the EOW mode of operation.[79]

The JMMES EON sensor is a passive, three-band, low-light, two-step camera. It can be utilized as a conventional EO camera to detect both maritime surface and land based targets. The EON sensor operates in two fields-of-view, which provide a significant (50x) step-zoom

[77] JMMES JCTD Concept of Employment, 1 December 2007.

[78] Ibid.

[79] Ibid.

capability. It can be utilized in its wide field-of-view as a wide-area-search scanning tool, and then utilized in the narrow field of view mode for further zoom and target identification.[80]

While the tested JMMES configuration was not equipped with LD/LRF capability, it is worth noting the added value of these additions. The LD/LRF is in a single package and provides an eye-safe ranging and targeting designation capability out to 30 kilometers. In conjunction with the LD/LRF, JMMES also has a "See Spot" capability within the EON sensor, allowing the system to detect its own laser designation. This affords the operator the opportunity to verify and validate the designated target, in both day and night time operations.[81]

The collection of aforementioned sensors provides data to the onboard data processor. The processor is the driving force of JMMES and allows real-time data input from all sensors for multi-sensor image acquisition, navigational data integration, real time tactical automatic detection and image processing, and a snapshot capture capability. It contains the various detection algorithms and associated software packages/modules that allow the multi-mission functionality. These specific modules and algorithms will be further discussed in ensuing sections.

The operator can access the sensors and the processor through the graphical user interface (GUI), or the sensors only through a handheld turret control/display. The handheld turret controller provides a manual override

[80] JMMES JCTD Concept of Employment, 1 December 2007.

[81] Ibid.

capability for the JMMES turret, which is controlled automatically through the GUI and processor during normal operations. The GUI displays separate subdivided fields of view for the various sensors, providing access to both real time and processed data and images.[82] The data is collected by one or multiple sensors and then sent to a common acquisition and control mechanism. From there, depending on the system mission settings, the data is processed through one of the mission software modules. After processing, the image and associated technical information is sent to the operator and accessed through the GUIA graphical depiction of data flow from the sensors, to the processors and through the specific mission software is included in Figure 19.

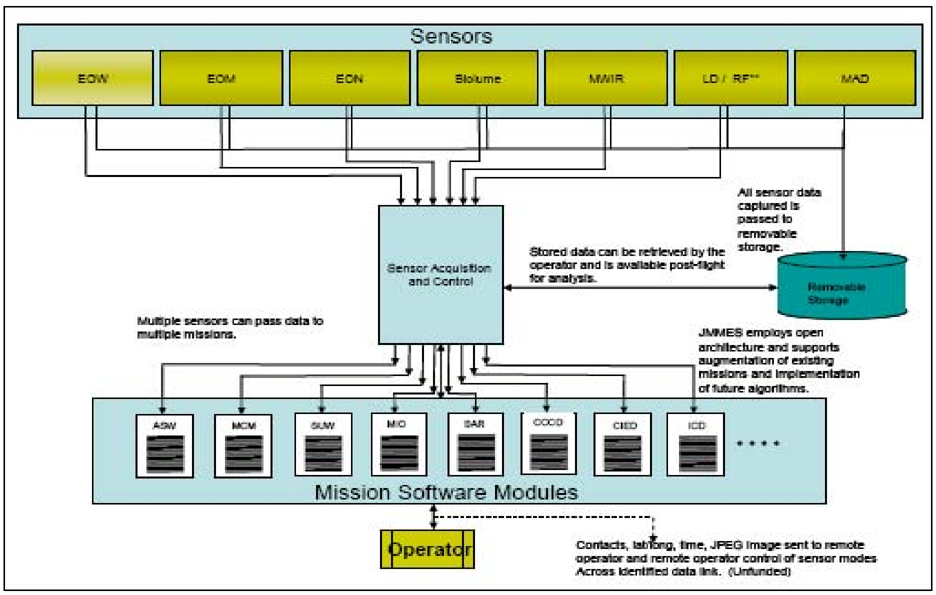

Figure 19. JMMES System Data Flow[83]

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[82] JMMES JCTD Concept of Employment, 1 December 2007.

[83] Ibid.

D. JMMES SYSTEMS DESIGN OVERVIEW

JMMES system development predominantly followed a top-down systems engineering functionality, though it did follow good systems engineering principles by also incorporating an aspect of bottom-up design. In top-down engineering, the system is developed to meet a predefined set of system requirements that flow in at the top level of design. Bottom up engineering is also important, as it is used to answer questions on both technical feasibility and organizational capability. However, too much bottom-up engineering leads to missed requirements and eventual integration problems. When requirements flow from the top down, "the balancing force is feasibility, which flows back up to ensure that higher level design decisions don't result in downstream requirements which are excessively difficult or impossible to meet."[84]

Specifically, the requirements for JMMES were laid out in the JMMES CoE and summarized again in the JMMES JCTD Integrated Assessment Plan (IAP). The IAP began by stating the broad, overarching problem:

> The United States, Interagency, and Coalition forces seek improved ISR capabilities to detect, classify, identify, and track high interest targets in a timely, effective, and economical manner. Today, each mission area is supported by a unique sensor suite, optimized for each particular aircraft platform, with its own training, CONOPS, TTP, and maintenance requirements. The results are insufficient assets to fulfill cross-functional ISR mission requirements, less than optimal capability to provide persistent surveillance of asymmetric

[84] Great Engineering, "Top Down vs. Bottom Up Design," www.greatengineering.net, accessed 15 September 2009.

> threats required for adequate situational awareness, and an inability to effectively detect, identify, characterize, track, monitor, and interdict asymmetric targets.[85]

Once the problem was identified, it was possible to establish the desired specific capabilities in a system to meet the challenges of the predetermined problem. Specifically for JMMES, the requirements were:

- Acquire a single, multi-mission system to operate from a variety of air platforms, including fixed wing, rotary wing, and ultimately UASs, vertical takeoff and landing tactical UASs, and aerostats
- Support multiple mission areas during any flight
- Reduce costs by optimizing, reducing, and/or standardizing hardware, training, CONOPS, TTP, maintenance, and logistics requirements across mission areas
- Improve effectiveness of searches by providing reliable automated target recognition and actionable target and location information
- Process data fast enough to support tactical operations
- Employ open architecture and support augmentation of JMMES JCTD existing missions and implementation of future algorithms.[86]

These specific capability requirements provided the framework for the top-down systems engineering and development of the JMMES system. In the final system design, the system designers and engineers developed a

[85] JMMES JCTD Integrated Assessment Plan.

[86] Ibid.

system with the following advertised capabilities in response to the provided requirements:

- Processing software configurable to multiple missions without software re-load
- Optimized target detection algorithms for each mission area
- On board processing for all missions
- Capability to extract and relay multispectral data over existing, low-bandwidth links
- Capable of being hosted by multiple platform types (military and civilian: fixed wing, rotary wing, and ultimately UAVs and aerostats)
- Multiple looks at each observed pixel from a single pass by the aircraft
- Automatic alerting on target detection to streamline human-in-the-loop analysis
- High detection rate and low false alarm rate
- Open architecture for spiral upgrade development.[87]

E. JMMES UNIQUE TECHNOLOGY OVERVIEW

JMMES multi-mission functionality and the associated enabling mission-specific algorithms are fundamental underlying principles of the aforementioned system capabilities. We will further examine these unique technologies individually in the following sections.

1. Multi-mission Capability

As previously discussed, JMMES has eight multi-mission application areas that are currently being tested in the JCTD process. These areas include: ASW, SUW, MIO, SAR,

[87] JMMES JCTD Integrated Assessment Plan.

MCM, CIED, CCCD, ICD. We will examine JMMES theoretical functionality in ASW, SUW, MIO, and Maritime SAR (MSAR) modes of operation, as those were the areas tested during our field testing.

In ASW mode, JMMES is designed to exploit both passive EO and magnetic detection of subsurface contacts in shallow water and littoral regions. Four independent sensors are utilized in this prosecution, including the 12-band EOW during daylight, the bioluminescence sensor during nighttime, the MWIR sensor during both day and night operations, and the MAD sensor. In SUW mode, surface contact detection is conducted utilizing three independent sensors. JMMES utilizes the 12-band EOW sensor and the four-band EOM sensor during daylight operations, and the MWIR sensor during either day or nighttime operations. In auto-detection mode, JMMES EO scans produce a contact list and associated EON high resolution with each contact. JMMES MIO mode of operation is a sub function of the SUW mode and utilizes the EOM and EON sensors to provide high-resolution tracking and monitoring during surface vessel interdiction. In MSAR mode of operation, JMMES utilizes two sensors as it searches for wreckage, life rafts, personal flotation devices, and individuals in the water. JMMES employs the 12-band EOW sensor and MWIR sensor in daylight and nighttime SAR operations respectively.[88]

While different mission sets utilize the same sensors within the JMMES turret, each specific mode of operation utilizes a different processing algorithm to enable the systems auto-detection capability. The multi-mission

[88] JMMES JCTD Integrated Assessment Plan.

functionality of JMMES allows the system operator to switch between mission sets in a given flight.[89] We will look more closely at the specific algorithms in the following section.

2. Unique Algorithms

JMMES employs multiple unique algorithms that enable both target detection and tracking. While specific technical algorithm information is proprietary and thus unavailable, the JMMES Concept of Employment does provide an overview of the various algorithms.

There are four detection algorithms discussed: anomaly detection, wavelet and glint, scene segmentation, and coherent change. The anomaly detection algorithm is an advanced algorithm used to detect objects that do not belong with their surroundings. This algorithm is useful for detecting contacts that stand out from the constant color of the ocean. The scene segmentation algorithm is designed to improve and enhance the efficiency of wide area searches. The wavelet and glint removal algorithm enhances detection capabilities by eliminating false contacts caused by sunlight glint off the water's surface or by higher sea-states. The coherent change detection algorithm is utilized to detect changes to the operating environment between consecutive flights.[90]

In addition to the detection algorithms, there are two additional algorithms utilized by the system: multi-hypothesis tracking (MHT) and spectral-fingerprinting. The

[89] JMMES JCTD Concept of Employment, 1 December 2007.

[90] Ibid.

MHT algorithm allows the system to automatically track surface contacts without operator intervention to lock onto a target. The MHT algorithm also allows the system to change the field of view in search of other targets, while maintaining the capability to regain track on a previously identified target after the search. The spectral fingerprinting capability allows JMMES to identify previously detected surface contacts by their spectral image. This capability is extremely useful in high-density contact areas such as the littoral regions.[91]

F. ORGANIZATIONAL CHANGE

Business organizations must continually examine themselves and their operating environment to maintain their capabilities. Every organization has a unique set of capabilities that allow it to perform its mission. The resources, processes, and values are the key factors that affect an organization's capabilities.[92] It is important that organizations be proactive when changes are occurring.

The operating environment in which organizations exist can affect the available resources, business processes, and organizational culture. The changes in the environment can the affect the quantity, quality, and type of resources available. Variations in any aspect of resources directly impacts the amount of effort an organization must expend in either refining the resources into finished products, or incorporating it into processes of the organization. The

[91] JMMES JCTD Concept of Employment, December 2007.

[92] Clayton M. Christensen and Michael Overdorf, "Meeting the Challenge of Disruptive Change," Harvard Business Review Edition (March-April, 2000), 68.

operating environment also impacts business process by defining the limits of acceptability and possibility. For example the "sweat shops" of the 19^{th} century became unacceptable after a change in the operating environment, forcing organizations that utilized this process to adapt. Organizational culture is impacted in the same manner as business processes, with workplace discrimination providing an example of a change mandated by new realities. Environmental changes can impact one or many areas and is often a catalyst for organizational change. Christensen and Overdorf present a study that describes how applying innovation to resources, processes, and values, enable and organization to adapt to change. With the appropriate analysis, and planning management can formulate appropriate combinations of innovation to maintain organizational capabilities.

Many organizations exhibit superior management, but lack the habit of thinking about their organization's capabilities as carefully as they think about the capabilities of their people.[93] By understanding the capabilities of an organization, managers can leverage the capabilities to counter changes in the environment.

Technological innovation is a common response to environmental change and can be separated into two categories: sustaining or disruptive.[94] Each of these categories affects the organization in different manners. Sustaining innovations are technologies that make a product

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93 Christensen and Overdorf, "Meeting the Challenge of Disruptive Change," 68.

94 Ibid., 71-72.

or service perform in better ways, and most organizations are well suited to accept it.[95] Organizations routinely encounter sustaining innovations and are normally well structured to foster its creation. Disruptive innovations are entirely new products or services and normally initially result in decreased performance.[96] Disruptive innovation is comparatively more difficult for an organization to cope with and is not seen as frequently. Many organizations instinctively resist disruptive changes previously successful processes, but when the operating environment changes in a significant manner, adopting disruptive innovation may be the only answer. Operating environments never remain constant and organizations that accept this fact and prepare for change increase their chances of continued success. In an effort to predict organizational disruptions such as backlogs, risks, or reduced——yet required——skill levels, organizational simulation software packages have been developed. This next section discusses one such package entitled “POW-ER.”

G. POW-ER MODELING SOFTWARE

Modeling software provides managers with the capability to simulate changes in various facets of an organization to conduct cost/benefit analysis before implementation of innovations. Prior to the development of modeling software, many organizations relied on the instincts of management to determine the best innovation to

[95] Christensen and Overdorf, “Meeting the Challenge of Disruptive Change,” 72.

[96] Ibid.

adopt. Utilizing modeling software affords organizations the opportunity for better and more consistent predictions are possible.

The strength of modeling and simulation lies in complex mathematical equations that are populated by user-defined input via a user-system interface. The interface gathers assumptions, facts, figures, and other pertinent data about the system to be modeled. The software converts the user’s inputs and specifications using appropriate equations and algorithms.

The results of the simulation help the user to determine solutions that can be optimized for a desired parameter. The solutions provided by models are heavily influenced by the quality of the assumptions and rules established at the outset. Users must keep in mind that computer simulations will produce a result even if the assumptions are erroneous. Accepting results from simulations with erroneous assumptions can result in wasted effort and meaningless results.

Modeling software packages have been optimized for particular purposes and organization types. For example, software packages have been tailored to manufacturing, weather, financial services, communication, etc. Selecting the appropriate type of modeling software is important because the underlying formulas are only valid for predetermined situations. Using ill-suited modeling software may produce results that are of little or no value.

POW-ER modeling software was developed at Stanford University by the Virtual Design Team (VDT). It follows a

structured process for creating optimized project resources. The developers of VDT had observed that the process for managing resources from people to tasks lacked structure. Their goal was to bring the discipline utilized by engineers to the process of managing project teams.

VDT and POW-ER allow a user to create models that are capable of analyzing the flow of work and communications within organizations. The models are comprised of elements that represent entities, work-tasks, milestone, and events. Any relationships between these elements are also captured in the model.

POW-ER utilizes a graphical user interface (GUI) to build the models of organizational structures and workflows. In the GUI, entities that perform work are called positions and are represented by a green human figure, tasks are represented by a yellow box, and milestones are represented by blue polygons. The start and stop milestones have shapes that are unique and not used for any other user defined milestones. Figure 20 shows the basic layout for the POW-ER 3.8 GUI with examples of the various entity graphical representations.

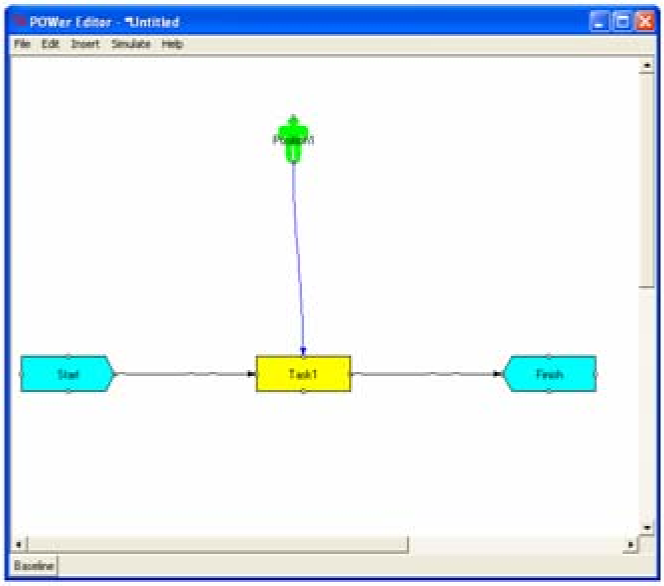

Figure 20. POW-ER Graphical User Interface

To build the model, the user inputs details about tasks, positions, milestones, and events, along with additional variables such as skill level required, complexity rating, effort required, and uncertainty. By varying the mentioned inputs, alternate cases can be created for comparison. Figure 21 demonstrates how a completed model will appear after the inclusion of task, positions and linkages.

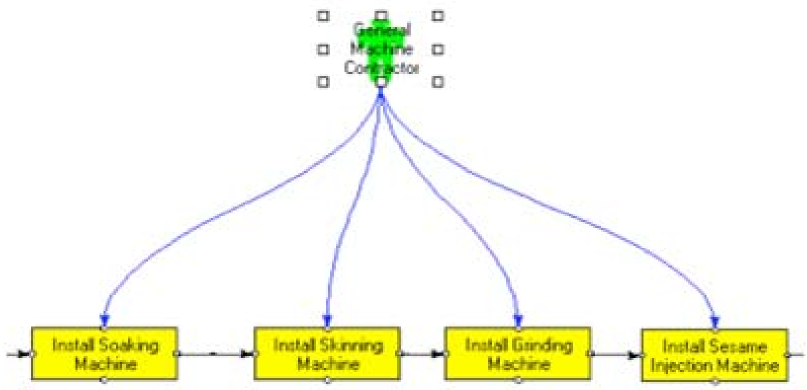

Figure 21. Sample POW-ER model with multiple tasks

POW-ER runs simulations of the modeled cases to produce statistical data for analysis of performance. The results of the simulations allow users to examine the interaction between organization structures and workflow to discover subtle relationships that affect performance. The data obtained from the simulation can be presented in table or graph format. Figure 22 shows a Gantt chart of workflow.

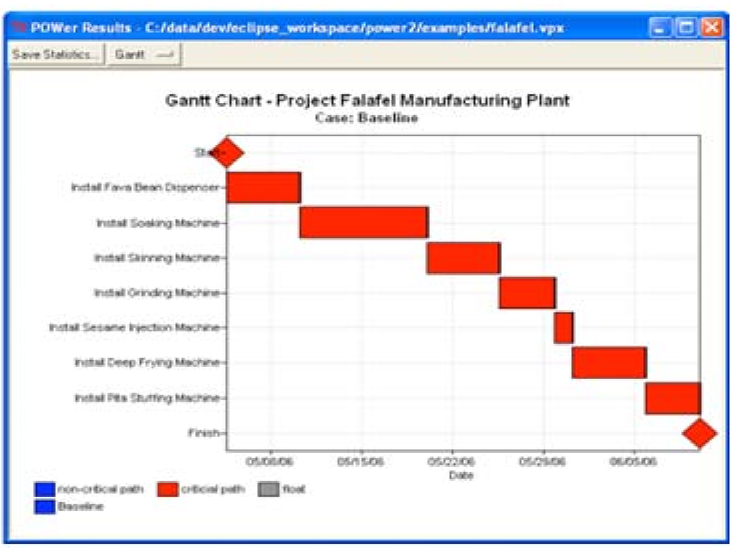

Figure 22. Sample Gantt chart

III. DATA COLLECTION AND ANALYSIS

A. TRIDENT WARRIOR 2009

1. Exercise Overview

Trident Warrior is an annual FORCEnet sea trial exercise conducted on a rotating basis between the east and west coast. Hosted by Naval Network Warfare Command (NNWC) since 2003, the common aim of the exercise is to enhance the warfighter’s capabilities, specifically in the areas of new technology development, communication, and situational awareness. During the exercise, U.S. naval forces team with other DoD services, international partners, civilian agencies, and defense industry organizations to test new technologies. Trident Warrior 2009 (TW09) took place in June 2009 and was a test-bed for 115 technologies across 10 focus areas: networks, coalition interaction, information operations, command and control operations, ISR, electronic warfare, distance support, information assurance, cross-domain solutions, and maritime domain awareness.[97]

2. Planned Flight Operations

TW09 was the first of three scheduled operational demonstrations during the JMMES JCTD process. Specifically, TW09 was used to assess JMMES ASW, SUW, MIO, and MSAR capabilities. The JMMES TW09 Demonstration Execution Document (DED) outlined the aim of the TW09 JMMES demonstration as:

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[97] Second Fleet Public Affairs Press Release, “Trident Warfighter Includes International Partners, Increases Warfighting Capability,” *Navy Newsstand,* 13 December 2008.

> to evaluate single mission flights, dual/multi-mission flights, in-flight detection and identification, and post-flight detection and identification using archived data. Each flight will have pre-determined assessment objectives, metrics to be evaluated, and situations to be executed to produce the required data. Demonstration execution is defined by the JMMES flight plan, target configurations, and data collection plan.[98]

The DED also included specific guidelines and focuses for each of the four tested mission areas. For ASW operations, the exercise provided opportunity for day and nighttime missions, with an increasing level of difficulty as the missions progressed throughout the exercise. For SUW and MIO operations, the focus was diverse, including both fast attack craft operating in a swarm type scenario, as well as traditional large surface craft operating independently in both day and nighttime scenarios. Lastly, TW09 provided the opportunity to test day and nighttime MSAR operations in a variety of scenarios: simulated downed aircrews in friendly and hostile environments, man overboard scenarios, and civilian vessel SAR.

In attempts to make the exercise flights as realistic as possible, the search capability of JMMES would be de-emphasized in some scenarios. Specifically, an EO/IR turret would not be a primary wide-area search tool in real-world, open-water ASW operations. Rather, the EO/IR asset would be cued and guided by RADAR and/or SONAR systems to a last known position of a subsurface contact before attempting to detect and track a contact. Thus, in TW09, cueing data was provided for last known positions of

[98] JMMES JCTD Demonstration Execution Document (DED), 6 June 2009.

identified subsurface contacts in attempts to create an accurate scenario.[99] This time-latent contact reduced the search area and provided a starting point for pre-determined search patterns.

There were 13 JMMES test flights scheduled during TW09, with an additional two days of as-needed make-up flights. All flights were conducted onboard either a JMMES equipped King Air fixed-wing aircraft or Bell 407 helicopter. Table 2 displays the preliminary schedule of flights for TW09 and Figures 23 and 24 show a King Air and Bell 407 respectively.

June 2009

Sun	Mon	Tue	Wed	Thu	Fri	Sat
14	15	16	17 JMMES a/c (2) arrive	18 JMMES a/c (2)-system install 0800 JMMES training, Hilton Gdn Inn 1300 Oceana Course Rules Brief, Base Ops	19 JMMES a/c day shake down flight - King Air, day & night shake down-Bell	20 JMMES a/c day fam flight-King Air & Bell 407 (1 each)
21 *JMMES a/c shake down/FAM flights-back up*	22 JMMES Trident Warrior Op Demo (ASW, SUW, MIO, Maritime-SAR), VACAPES/Hampton Roads (22-28 Jun) Day 1-Events-1(d)-Bell-SUW-FAC/FIAC-Dep Corridor 2(d)/3(n)-King Air-SUW/ASW-W72B/C	23 Day 2-Events-4(d)/5(dn)-King Air-SUW/ASW-W72B/C JMMES a/c day fam flight-Bell 407 W50/R6606	24 Day 3-Events-6(d)/7(n)-King Air-ASW-W72B/C JMMES a/c day fam flight-Bell 407 W50/R6606	25 Day 4-Events-, W50/R6606 8(d), 9/10(n)-Bell-SARx2, MIO. *back up SUW/ASW* King Air departs	26 Day 5-Events-W50/R6606, 11-Bell-SUW-FAC/FIAC-Dep Corridor, 12(d), 13(dn) SAR.	27 Day 6-*back up SUW/MIO, SAR-Bell-W50/R6606* JMMES pack up, Bell 407 departs
28 JMMES Trident Warrior Op Demo (ASW, SUW, MIO, Maritime-SAR), VACAPES/Hampton Roads (22-28 Jun) Day 7-*back up SUW/MIO, SAR-Bell-W50/R6606*	29	30				

Table 2. Preliminary TW09 Flight Schedule[100]

[99] JMMES JCTD Demonstration Execution Document (DED), 6 June 2009.

[100] Ibid.

Figure 23. King Air Fixed Wing Aircraft[101]

Figure 24. Bell 407 Helicopter[102]

The flight crew onboard the King Air and Bell 407 was comprised of five personnel: aircraft pilot, first officer/co-pilot, JMMES operator, mission area subject matter expert (SME), and Operational Test Agent (OTA) observer. We, the authors of this thesis, filled the role

[101] JMMES JCTD Demonstration Execution Document (DED), 6 June 2009.

[102] Image obtained from BAE Systems JMMES Preliminary Results Presentation.

of OTA observer, along with Mr. Brian Wood, of the NPS Distributed Information and Systems Experimentation (DISE) research group.

The aircraft pilot and first officer were contracted with the aircraft and their primary responsibilities were the execution of the predetermined flight plan, coordination of in-flight modifications to the predetermined flight plan, and ensuring safety-of-flight of the aircraft.

The JMMES operators were JMMES system experts from BAE Systems. Their primary responsibility was the physical operation of JMMES, to include pre-flight, in-flight, and post-flight operations, in-flight system troubleshooting, interpreting JMMES target detections, and providing expertise on system capabilities.

The mission area SME varied depending on the mission profile of the flight, as there were designated SMEs for ASW, SUW, MIO, and MSAR mission areas. The SMEs were active duty naval aviators with extensive experience operating comparable sensors and monitoring the associated sensor displays while conducting real-world operations in the various TW09 mission areas. Their primary responsibilities included ensuring the operational realism of the flights and providing subjective assessment of the system. Specifically, the SMEs responsibilities were to consult in the mission flight plan development, validate mission tactics, techniques, and procedures (TTP), observe in-flight system operations, and direct in-flight data capture. As the JMMES operators did not have an operational background in the specific mission areas, and

as it was not feasible to provide the mission area SMEs adequate training to become system experts on JMMES, the combination of the mission area SME and JMMES operator simulated the equivalent of a mission and system expert operating JMMES onboard the aircraft in a real-world environment.

The final flight crewmember was the OTA observer, who was responsible for the execution of the data capture portions of the flights. Specifically, the OTA observer's responsibilities included aiding in the development of an appropriate mission plan, providing airborne modification of said mission plan as needed, maintaining a detailed flight log of all operational and administrative matters of the flight, and ensuring the accuracy and integrity of the exercise flights on behalf of the JCTD evaluation team.[103]

Figures 25 and 26 show the flight crew seating positions onboard the King Air and Bell 407, respectively.

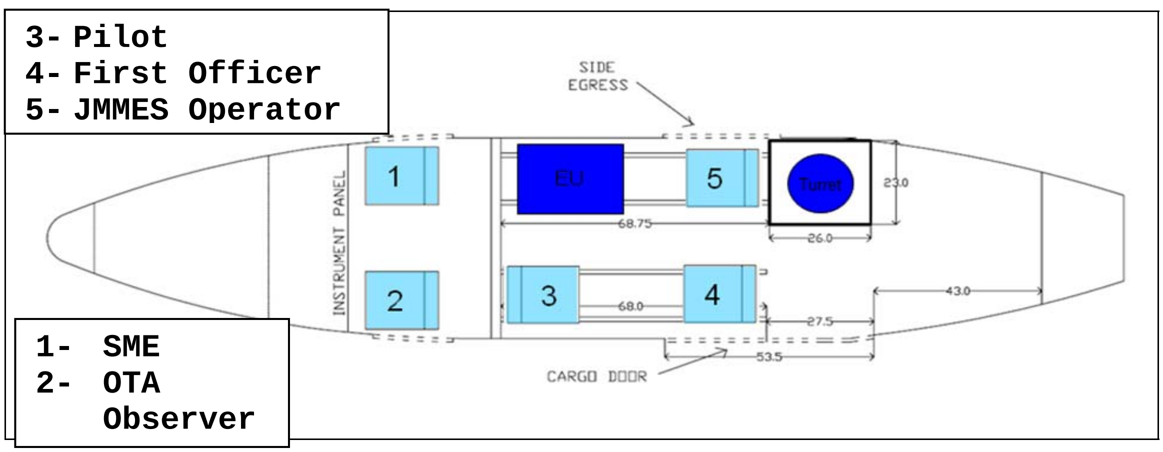


Figure 25. King Air Flight Crew Positions[104]

[103] Image obtained from JMMES JCTD Demonstration Execution Document (DED), 6 June 2009.

[104] Ibid.

1- Pilot 2- First Officer	3- SME 4- OTA Observer	5- JMMES Operator

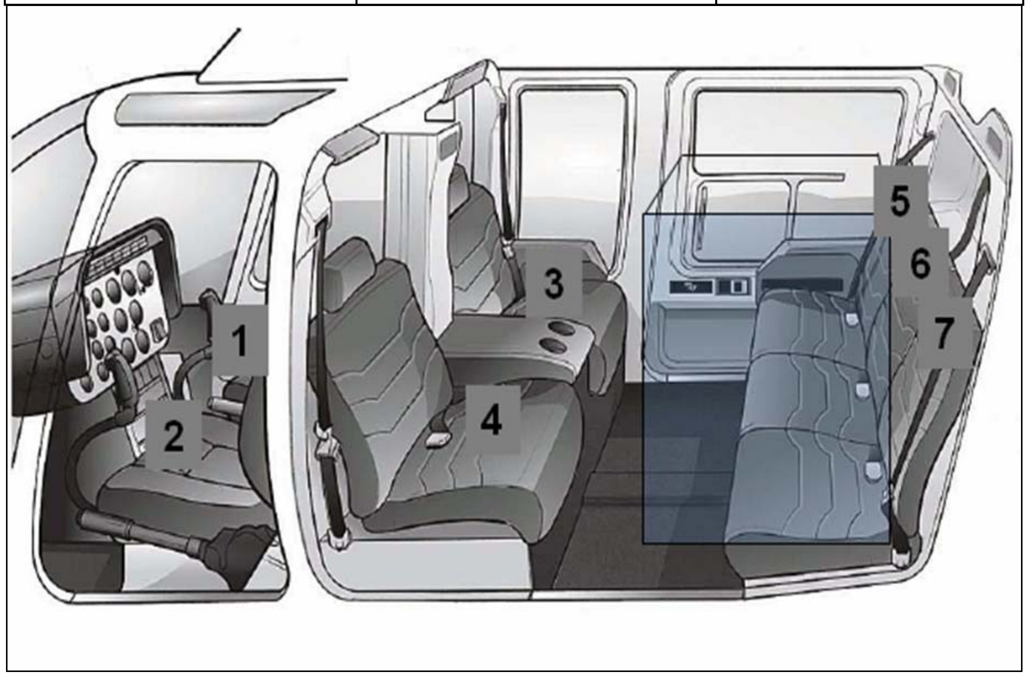


Figure 26. Bell 407 Flight Team Positions[105]

B. DATA COLLECTION AND ANALYSIS

1. Evaluation Criteria and Methodology

The TW09 JMMES evaluation methodology consisted of both in-flight and post-flight qualitative and quantitative data collection. In-flight qualitative data collection consisted of the OTA observer monitoring the operations of and providing survey questions to the JMMES system operator and the mission area SME. In-flight quantitative data collection consisted of event and system logs maintained by the JMMES system operator, mission area SME, and the OTA observer.

[105] Image obtained from JMMES JCTD Demonstration Execution Document (DED), 6 June 2009.

Post-flight operations consisted of data-processing, data-archiving, and post-mission surveys, delving into both the qualitative and quantitative realm. Post-flight data processing and data archiving allowed the JMMES operator and mission analyst to re-process and review collected system data for possible missed information and provide inputs to improve future mission sets. Post-flight surveys were distributed to both the JMMES operator and mission area SME and included both qualitative and quantitative aspects.[106] For the scope of this thesis and the POW-ER model presented in Chapter IV, we are focusing on the quantitative data gleaned from the exercise.

The surveys and flight evaluations were focused on gathering information to evaluate the three JCTD defined Critical Operational Issues (COI) across the exercise mission areas. These COIs included Operational Impact, Functionality, and Suitability. Table 3 contains a snapshot of the specific components of COI-1 (Operational Impact), as well as the associated survey questions used to evaluate the COI. Specifically, it presents the primary COI-1 question (labeled 1.1), with qualitative and quantitative sub-questions also listed. To the right of each question are the associated survey line items that cover the COI primary question and sub-questions. A complete version of the COI-1, COI-2, and COI-3 JCTD MUA assessments can be found in Appendix A.

[106] Image obtained from JMMES JCTD Demonstration Execution Document (DED), 6 June 2009.

COI Question | COI Identification | COI Category Identification | COI Sub-question | Associated Survey Line Item

COI-1 JMMES JCTD MUA Assessments		Survey
1.1	Does the JMMES sensor suite improve the warfighter's situational awareness and level of reconnaissance in support of the eight user-prioritized mission areas?	C1.1
Situation Awareness		
	Qualitative	MA1 SA1 Coll1 ISR1-4
SA1	Does JMMES improve awareness of the target situation in the assigned surveillance area?	
SA2	Does the system provide battlefield understanding that is clear, sufficient, and timely?	SA2 Coll3 MA2
SA3	Rate the ease of maintaining SA across the AOR during search.	SA2
	Quantitative	
SA4	Number, fraction, of detected targets for which SA can be maintained during search.	
Level of Reconnaissance		
	Qualitative	
LR1	Does JMMES improve the level of reconnaissance in the assigned surveillance area?	ISR2

Table 3. Snapshot of COI-1 Assessment[107]

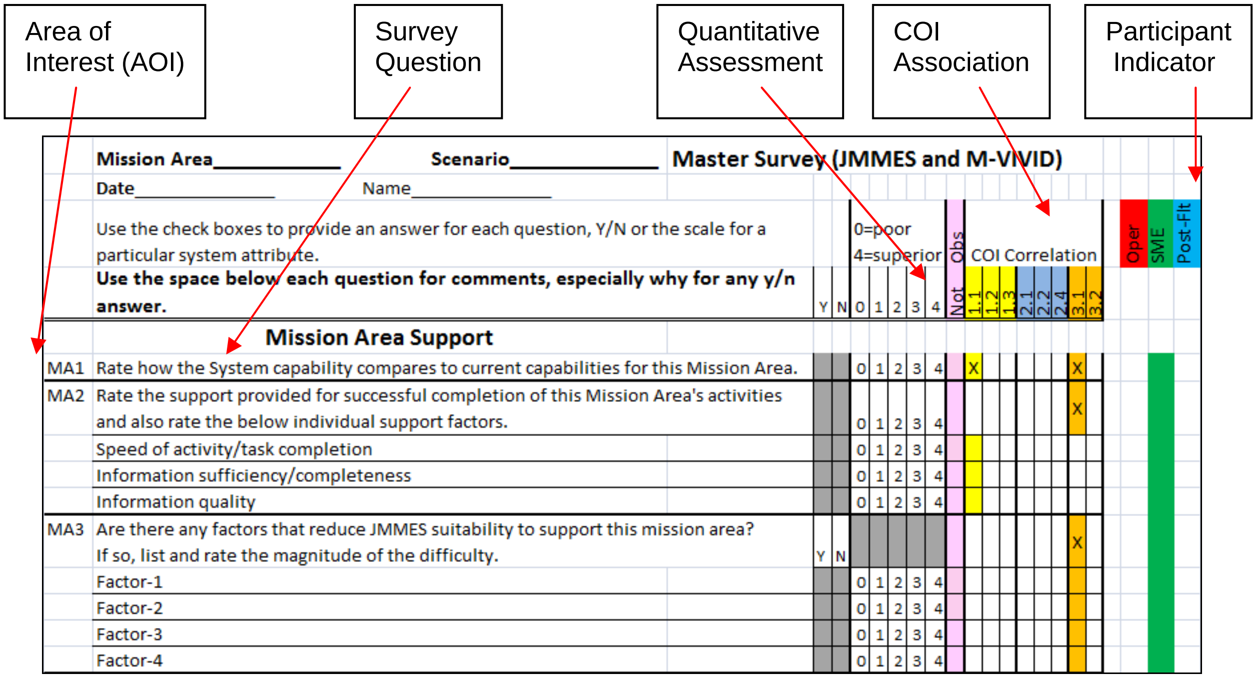
In addition to the JMMES JCTD MUA COIs, the in-flight and post-flight evaluation included seven additional Areas of Interest (AoI). These AoIs were developed by members of the NPS DISE research group to compliment the defined COIs and ensure robust analysis of JMMES capabilities. The AoIs are Mission Area Support (MA), ISR Operations Support

[107] Image obtained from JMMES JCTD Demonstration Execution Document (DED), 6 June 2009.

(CISR), Target Situation Awareness (TS), Operator Workload (W), In-flight System Management (SM), Human System Interaction (HS), and Automated Features (AF).[108] These AoIs were found in both the survey itself and in the post-exercise analysis of the surveys.

The TW09 JMMES surveys were developed in response to the defined COIs and AoIs by Dr. Nelson Irvine, of the NPS DISE research group. Table 4 provides a snapshot of the survey used in TW09 and includes the questions presented to both the JMMES operator and mission area SME. The far right hand column on the survey shows which specific questions were included in the surveys provided to each individual. For instance, the first question, MA1, is highlighted in the SME column, indicating it is included only on the SME post-mission survey. Working right-to-left across the columns, the next column provides the correlation between the questions in the survey and the associated COI sub-question. The next columns to the left provide the basis for quantitative inputs from the SME and JMMES operator. Further qualitative inputs and subjective comments were requested and both the SME and JMMES operator provided detailed opinions in conjunction with the quantitative numerical rankings. A full copy of the survey can be found in Appendix B.

[108] Gordon Schacher, JMMES JCTD Maritime Utility Assessment DISE Input, Appendix A.



Mission Area____________ Scenario____________ **Master Survey (JMMES and M-VIVID)**
Date______________ Name______________

Use the check boxes to provide an answer for each question, Y/N or the scale for a particular system attribute.
Use the space below each question for comments, especially why for any y/n answer.

0=poor
4=superior

COI Correlation

		Y	N	0	1	2	3	4	Not Obs	1.1	1.2	1.3	2.1	2.2	2.4	3.1	3.2	Oper	SME	Post-Flt
	Mission Area Support																			
MA1	Rate how the System capability compares to current capabilities for this Mission Area.			0	1	2	3	4		X						X				
MA2	Rate the support provided for successful completion of this Mission Area's activities and also rate the below individual support factors.			0	1	2	3	4								X				
	Speed of activity/task completion			0	1	2	3	4												
	Information sufficiency/completeness			0	1	2	3	4												
	Information quality			0	1	2	3	4												
MA3	Are there any factors that reduce JMMES suitability to support this mission area? If so, list and rate the magnitude of the difficulty.	Y	N													X				
	Factor-1			0	1	2	3	4												
	Factor-2			0	1	2	3	4												
	Factor-3			0	1	2	3	4												
	Factor-4			0	1	2	3	4												

Table 4. Portion of TW09 JMMES Master Survey[109]

2. TW09 Flight Operations

We conducted 13 JMMES test flights during exercise TW09, testing the system's ASW, SUW, MIO, and MSAR capabilities. Though originally scheduled mission times were modified due to inclement weather, target platform availability, and system maintenance issues, both daytime and nighttime flights were completed across the four mission areas. For clarity purposes and due to their similar nature within TW09, SUW and MIO are combined in post-exercise analysis.

The primary ASW mission target was the USS ALEXANDRIA (SSN 757), while the primary SUW mission targets included

[109] Image obtained from JMMES JCTD Demonstration Execution Document (DED), 6 June 2009.

USS BULKELEY (DDG 84), USS FARRAGUT (DDG 37), and USS NASSAU (LHA 4), as well as various commercial and private vessels used as targets of opportunity. For the MSAR missions, targets included a simulated man overboard in the water, simulated downed pilot, and a manned life raft. In the scenarios, a dummy (Oscar) simulated the MSAR victim. A U.S. Coast Guard (USCG) Auxiliary craft was used to coordinate MSAR exercise operations. Figure 27 shows U.S. Navy vessels that participated as targets for JMMES testing and Figure 28 shows an example of a USCG Auxiliary craft.

Figure 27. U.S. Navy Vessels in TW09 JMMES Flights[110]

[110] Figure obtained from pre-mission briefings presented to flight crew during TW09.

Figure 28. USCG Auxiliary Craft[111]

All TW09 JMMES flights took place on the Virginia Capes (VACAPES) operating area (OPAREA), with mission launch and recovery at Oceana Naval Air Station and overwater operations in W-72B/C, W-50/R-6606, and the Hampton Roads departure corridor. Figure 29 shows OPAREA W-72 used during TW09 JMMES flight operations. Further charts of the exercise OPAREAs can be found in the JMMES JCTD DED.

[111] Defense Industry Daily.com, "U.S. Coast Guard Auxiliary," www.defenseindustrydaily.com, accessed 15 September 2009.

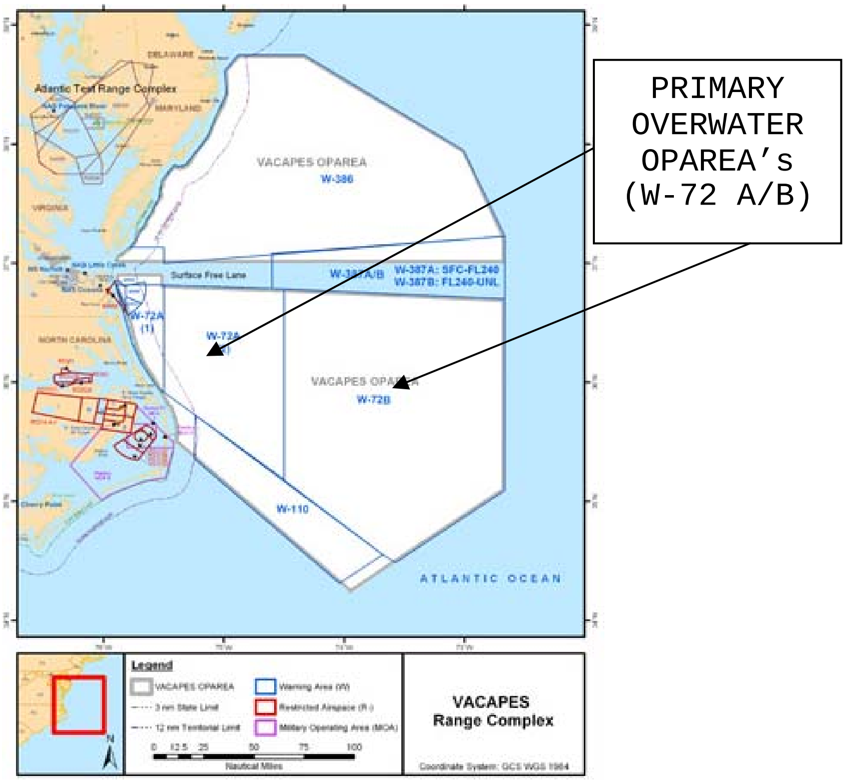


Figure 29. TW09 JMMES W-72 OPAREA[112]

3. TW09 Post-flight Survey Analysis

Post-mission surveys were completed by the mission area SME and JMMES operator for each of the 13 TW09 exercise flights. The mission area SME quantitative survey results are of primary interest to this thesis, as they provide an unbiased opinion as to JMMES functionality in the specific mission area tested and were used to accurately populate the POW-ER model in Chapter IV.

NPS DISE research group member, Dr. Gordon Schacher, developed the methodology for quantitative analysis of the collected survey information. Using the numerical ratings

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[112] Figure obtained from JMMES JCTD Demonstration Execution Document (DED), 6 June 2009.

provided in the mission area SME surveys, he developed a percentage rating for each specific question, and then for the individual mission areas, AoIs, and COIs. Dr. Schacher then developed these percentages into histograms to examine the various AOIs and COIs in greater detail. The final numerical scores are not individually statistically significant, but rather are a visual and numerical means to understand the mission area SME evaluation of military utility of the JMMES system.[113] In other words, by itself, a score of 60% is arbitrary, but is useful in comparison across the mission areas, COIs, and AoIs.

We will first look at the specific COI questions that were provided in the surveys for the specific mission areas, and then we will look further at the specific mission area by breaking them down through their associated AoIs.

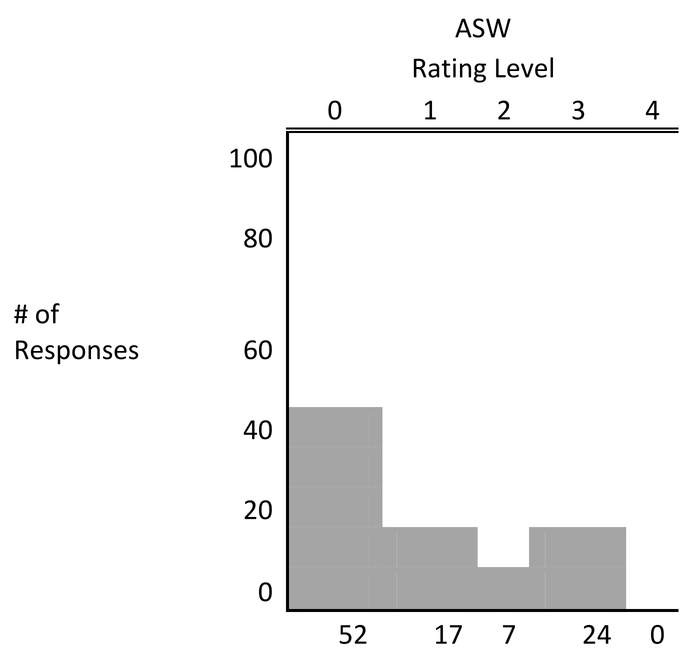
a. COI Ratings

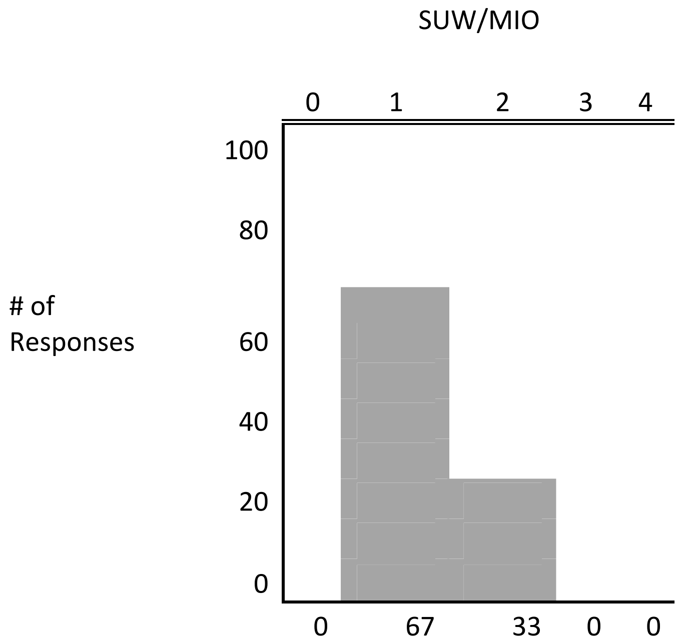
Table 5 presents three histograms displaying the frequency of assigned numerical grades given to the various COIs across the mission areas by the mission area SMEs. The SMEs provided numerical scores of “0, 1, 2, 3, 4” in response to the COI questions in the post-mission surveys, with a score of zero equating to poor and a score of four equating to superior for the specific question asked.

Using Dr. Schacher’s incrementally weighted scale and allotting “0, 25, 50, 75, and 100” points for scores of “0, 1, 2, 3, and 4,” respectively, a percentage was

[113] Figure obtained from JMMES JCTD Demonstration Execution Document (DED), 6 June 2009.

calculated to provide a rough overall COI score for each mission category. In the case of SAR, 43% of the COI questions received a numerical grade of “1 of 4,” 29% of the COI questions received a numerical grade of “2 of 4,” and 29% received “3 of 4.” These scores equated to a final SAR COI score of 46%. A summary of all three COI scores is provided in Table 6.





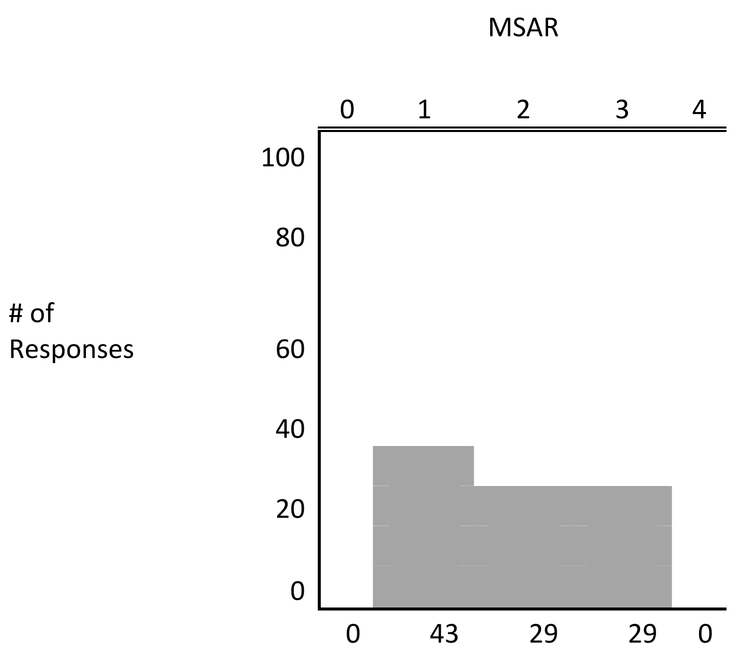


Table 5. Frequency of SME COI Grade Assignments[114]

[114] Gordon Schacher, JMMES JCTD Maritime Utility Assessment DISE Input, Appendix A.

COI Question Ratings by Mission Area	
Mission Area	**Rating**
SAR	**46%**
SUW	**33%**
ASW	**26%**
Average	**35%**

Table 6. SME COI Grade/Rating Summary[115]

b. AoI Ratings

Dr. Schacher utilized the same incrementally weighted numerical scale to develop ratings/grades for the AoIs for each specific mission area. The summary table of the AoIs and the associated grades for the various mission areas are included in Table 7. The table shows a score of almost 50% across all evaluated mission areas and AoIs. These scores were used to populate the POW-ER simulation model presented in Chapter IV of this thesis. Frequency histograms and further details on the data in Table 7 can be found in Appendix C.

[115] Gordon Schacher, JMMES JCTD Maritime Utility Assessment DISE Input, Appendix A.

AoI	ASW/MIO	SUW	MSAR	Avg
Mission-Area Support	**43%**	**35%**	**50%**	**43%**
ISR Ops Support	**44%**	**36%**	**59%**	**46%**
Target Situational Awareness	**25%**	**55%**	**44%**	**41%**
ISR Collection Activities	**41%**	**33%**	**57%**	**44%**
Operator Workload	**52%**	**33%**	**42%**	**42%**
In-Flight System Management	**55%**	**66%**	**60%**	**60%**
Human-System Integration	**60%**	**61%**	**59%**	**60%**
Automated Features	**58%**	**30%**	**75%**	**54%**
Totals	**44%**	**47%**	**56%**	**49%**

Table 7. SME AoI Grade/Rating Summary[116]

[116] Gordon Schacher, JMMES JCTD Maritime Utility Assessment DISE Input, Appendix A.

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IV. MARITIME ISR MODELING AND ANALYSIS

A. OVERVIEW

The DoD has expressed interest in enhancing their ISR capabilities across all services. BAE Systems has offered JMMES as answer to this call, with claims of improved capability for maritime ISR. JMMES is currently in the JCTD process and the results of the JMMES JCTD MUA will not be published until after the completion of this thesis. However, the data from TW09 is sufficient to construct a valid model of EO/IR search for ASW, SUW, and MSAR missions and this Answering *"how will the addition of JMMES to manned Aircraft Systems impact the performance of current maritime ISR process?"*

This chapter will present an application of the VDT modeling process for EO/IR search in ASW, SUW, and SAR missions. SME survey results and data from Chapter III is used to construct and validate the model. The research conducted in Chapter IV builds on work with VDT performed by Carroll and Sundland (2009), in their thesis "Transforming Data and Metadata into Actionable Intelligence and Information within the Maritime Domain," where they utilized POW-ER modeling software to examine extended maritime interdiction operations. Their work demonstrated the ability of POW-ER software to model processes of military missions.

B. VDT STEPS ONE THROUGH FOUR

1. Baseline Definition: Workflow and Organization Model

Step one of the VDT modeling process is to define the baseline for the workflow and organization models. Three activities are required to complete step 1:

1. Define the organization model
2. Define the workflow model
3. Define the links.

When modeling a complex system, it is useful to scale the model to examine only the pertinent aspects of the system. For the purposes of this thesis, only the interaction between EO/IR sensor and the operator is of interest. In order to scale down the MISR process, all tasks unrelated to the EO/IR sensor and operator interaction were eliminated.

Another useful technique when modeling complex systems is to include only those items that will create change as alternate cases are compared. Items that are not impacted by changes in cases are constants, and eliminating these constants has no impact on output. It is important to ensure that the constants to be eliminated are not vital to any combined statistics that are sought.

After scaling the MISR process and eliminating the unneeded constants, we created the resultant "non-JMMES workflow" or baseline case. This baseline was validated by the Operational Test Agent (OTA) for JMMES JCTD at the Naval Postgraduate School (NPS).

a. *Define Organization Model*

The first activity in step one of the VDT process is to create the organization model that will accomplish the baseline tasks. All positions that perform tasks are identified. The derived baseline model is provided in Figure 30 and each specific position in the organization model is discussed in the following paragraphs.

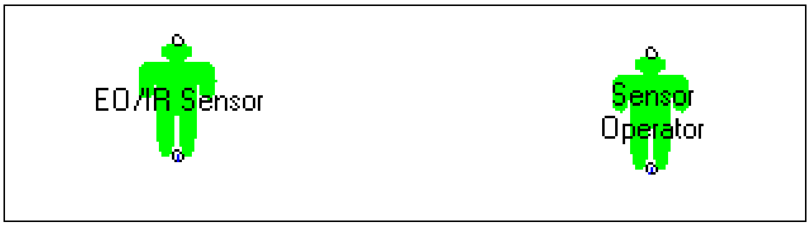

Figure 30. Baseline Positions

The Sensor Operator position is a member of the helicopter aircrew responsible for monitoring EO/IR sensor systems and analyzing information presented on video monitors in H-60 aircraft. The Sensor Operator controls the EO/IR sensor with a WESCAM controller and must visually identify targets on the video display in the aircraft.

During test flights, the EO/IR Sensor position was filled by the MX-15D turret. Survey data shows the performance of MX-15D in MWIR is comparable to the AAS-44 FLIR, which is currently utilized. When deriving the model for POW-ER, positions are not exclusively assigned to humans. In order to understand the functioning of the system, any entity that performs a task must be modeled. The MX-15D MWIR performs the tasks of imaging the area of

interest and its performance characteristics will be compared to the MX-15D sensors combined EOW, EON, and MWIR utilized by JMMES.

Each position has a number of parameters that need to be assigned values in order to accurately represent how well the position performs tasks. The values assigned to the property panel parameter determine probabilities of errors occurring in the performance of tasks. Figure 31 shows the property panel for the EO/IR Sensor position. Details for the parameters entered for each "Position,” in the baseline case, are listed in Appendix D.

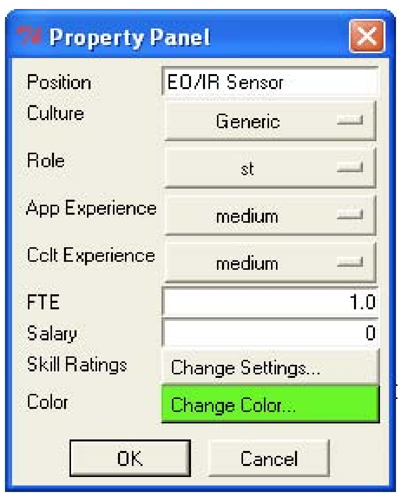

Figure 31. EO/IR Sensor Property Panel

b. Define Workflow Model

The next activity that must be accomplished in step one is to define the workflow model. In order to accurately define the baseline case, “non-JMMES workflow,” the MISR work process diagram was examined and tasks not impacted by JMMES were eliminated. Six tasks were found to

be relevant for modeling and are listed in Table 8, along with the position that performs the tasks. While the list appears short, the impact of the tasks on the much larger MISR process is significant.

Baseline search task List

Task		Position
Position EO/IR FOV		EO/IR sensor
Scan the IO/IR FOV		EO/IR Sensor
Locate anomalies in the FOV		Sensor Operator
Compare anomaly to known targets		Sensor Operator
Report target		Sensor Operator

Table 8. Task List for Baseline Case

Each task has associated properties that must be defined in the model. Figure 32 shows the property panel for the task "Scan the EO/IR FOV" to provide an example of parameters that must be defined. During simulation of the model, the properties for each task and position are utilized to calculate process performance. Appendix D contains a list of all task and the parameters.

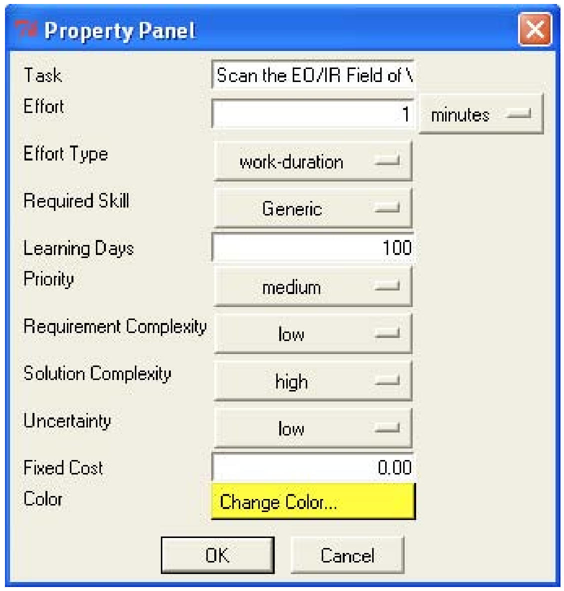

Figure 32. Scan the EO/IR FOV Properties Panel

c. Define Links

The final activity in step one is to define the links between the elements of the model. There are four types of links utilized: communication, task assignment, successor, and rework. Links provide details about how positions and/or tasks interact, and must be identified in order to run a simulation.

There are two communication links in the workflow model. The first is between the "Locate the anomalies in the FOV" and the "Scan the EO/IR FOV" tasks, this link allows the sensor pod to present an image to the sensor operator for visual examination. The second communication link is between the "Compare anomaly to known target" and the "Scan the EO/IR FOV" tasks and allows the sensor operator to more closely examine the image in order to correctly identify the target.

The baseline case contains five task assignment links, shown as blue arcs in Figure 33. Table 8 shows list of tasks and positions responsible for performing the tasks.

The successor links describe the order in which tasks are executed. After a task is completed, control is passed to its identified successor and a task may have more than one successor. The start milestone has successor links to both “Position EO/IR FOV” and “Scan the EO/IR FOV,” both of which may begin concurrently after start.

Rework links are included in the model to allow for capturing errors in tasks. When an error occurs in a task that has a rework link, the task linked to will be re-executed along with the current task. For example, during execution of the "Compare anomaly to known targets" task, if the anomaly is not confirmed as a target, the operator should recommence the search by moving EO/IR to another area to search. This is modeled by a rework link to the "Position EO/IR FOV" task. The rework task allows for some recursion in the model offering an improvement in the approximation of search process.

2. Simulate Process to Assess Risks in Baseline Case

Step two in VDT is to simulate the baseline process and assess results. POW-ER utilizes the information provided in step one to run a simulation and identify workflow backlogs, critical paths, rework times and simulation times. The scenario that is modeled is a single H-60 equipped with EO/IR sensor searching for a target of interest.

POW-ER was designed to simulate processes that perform defined tasks a single time while moving toward a final milestone. By contrast, the process of searching for a target requires that tasks be repeated in a loop, until the target is found. The baseline model is shown in Figure 33.

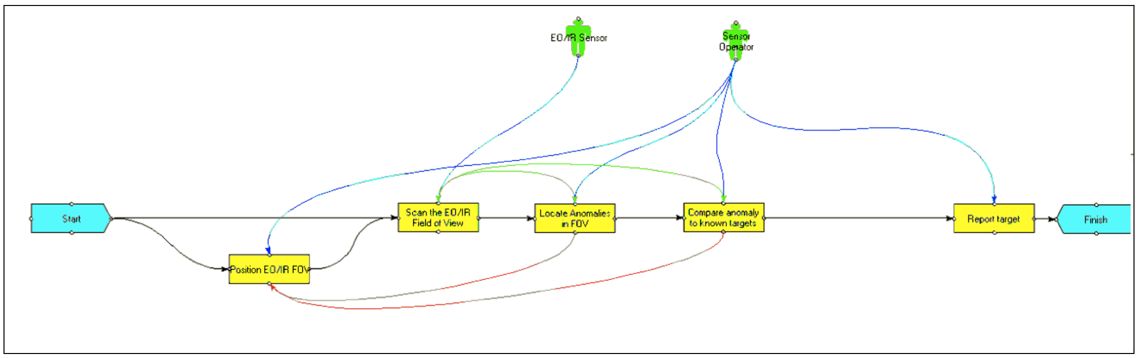

Figure 33. Baseline POW-ER Model

During the simulation, POW-ER captures performance statistics and presents them to the user in chart or table form. The model is run 100 times in order to identify the mean for all parameters of interest. For the purpose of this thesis, parameters of interest include total time required for the process and critical path diagram. The average times required for execution of each task is shown in Table 9.

Baseline case time for task

Task	Time
Position EO/IR FOV	0.0146
Scan EO/IR FOV	0.0058
Locate anomalies	0.0088
Compare anomalies	1.4000
Report Target	0.0220
Total Time	1.4512

Table 9. Baseline tasks time required

The Gantt chart provides a means to identify tasks that are critical to the performance of the system being modeled. A task is identified as critical if delays in performance of the task will negatively impact the system. Conversely, non-critical tasks can be delayed with no impact to the system. The amount of delay that a non-critical task can accept is called float time. Critical tasks are color coded red, non-critical tasks are blue, and float time is gray. The start and stop milestones are depicted as diamond shapes, all other tasks appear as bars with length proportional to the average time required to execute the task. As can be seen in Figure 34, all tasks in the baseline case are critical to the performance of the system and neither float time nor non-critical paths exist.

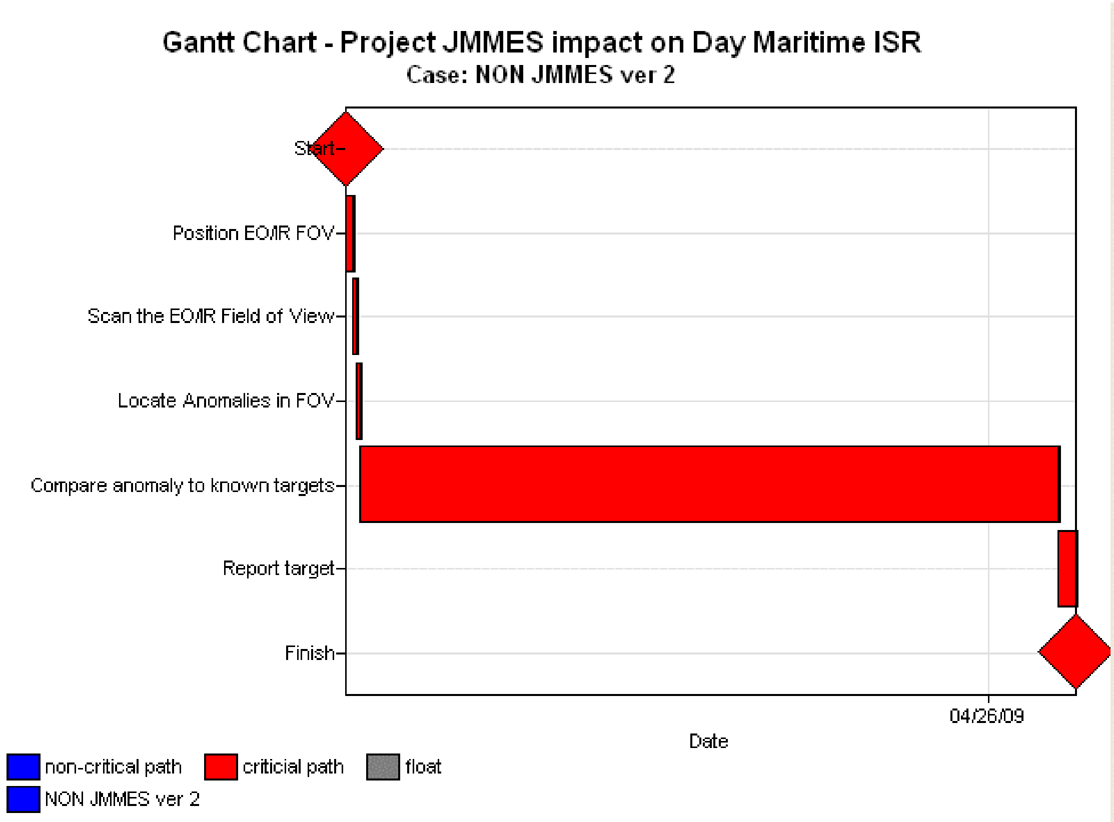

Figure 34. Gantt chart for baseline

3. Simulate Alternatives

Step three in the VDT process is similar to Steps one and two and can be broken down into four activities:

1. Define changes to the baseline organization
2. Define changes to baseline workflow
3. Define changes to the baseline links
4. Simulate process and assess the risks.

a. Define Changes to Baseline Organization

The first activity to be completed is defining the changes to the baseline organization. All positions from the baseline case remain necessary and one additional position for JMMES is created for the alternative case. JMMES will perform tasks so must be represented as a position. The skills and properties of JMMES are listed in Appendix E. A depiction of the new organization structure is shown in Figure 35.

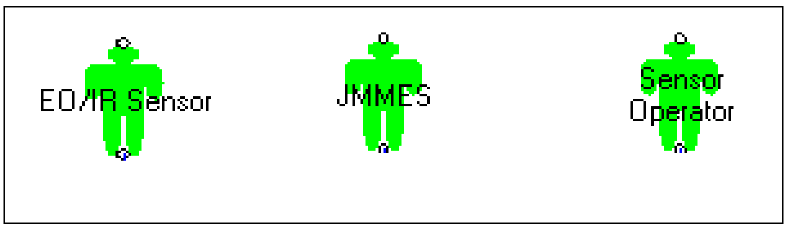

Figure 35. Alternate Case Organizational Structure

b. Define Changes to Baseline Workflow

The next activity required is to define the changes to the baseline workflow. Changes to the workflow must be validated to ensure the simulation data is realistic. With the introduction of JMMES, it was determined that all existing tasks remained relevant and two additional tasks were required. Table 10 shows a list of the tasks for the alternative case workflow.

JMMES EO/IR Area Search Task List

Task		Position
Position EO/IR FOV		JMMES
Scan the IO/IR FOV		EO/IR sensor
Locate anomalies in the FOV		JMMES
Compare anomaly to known targets		JMMES
Display target to operator		JMMES
Verify target		Operator
Report target		Operator

Table 10. Alternative Task List

The first new task is "Display target." One of the JMMES system’s innovative features is its ability to auto-detect anomalies in the FOV and classify them. Once JMMES has detected an anomaly, it compares the EO and IR signature to a pre-loaded database of known targets. If a match is found, JMMES highlights the target location and provides a short description on the system display. For anomalies that cannot be matched to a signature in the database, JMMES highlights the target location and provides an "unknown" description on the system display.

The second new task added is "Verify target." Due to variations in atmospheric conditions, illumination, and viewing angle, the spectral fingerprint of targets can be slightly different from database entries and result in an "Unknown" classification. The number of possible spectral fingerprints for a single target can become quite large and with multiple targets the database size becomes problematic. Prior to mission launch, JMMES is loaded with designated necessary spectral fingerprints. Due to this

limitation, JMMES reliability in correctly auto-detecting targets is currently less than a human operator, therefore a verification task is necessary.

c. Define Changes to Links

The next activity to be completed is “define changes to links.” As with the baseline case there are communications, task assignment, successor, and rework links. An additional communication link is added to those defined in the baseline case to create alternative case. As previously discussed, the need to verify JMMES classification of anomaly dictates that the "Verify target" task communicate with the system operator.

There is one extra rework link required to define the alternative case. The additional link is from the "Verify target" task to the "Position EO/IR FOV" task. During the "Verify target" task, the possibility exists that JMMES target notification is a false alarm. In the case that a target is falsely called, the process should recommence the search.

d. Run Simulation of the Alternative Case

The alternative case model is shown in Figure 36. The data captured after the simulation of the alternative case is presented in Table 11.

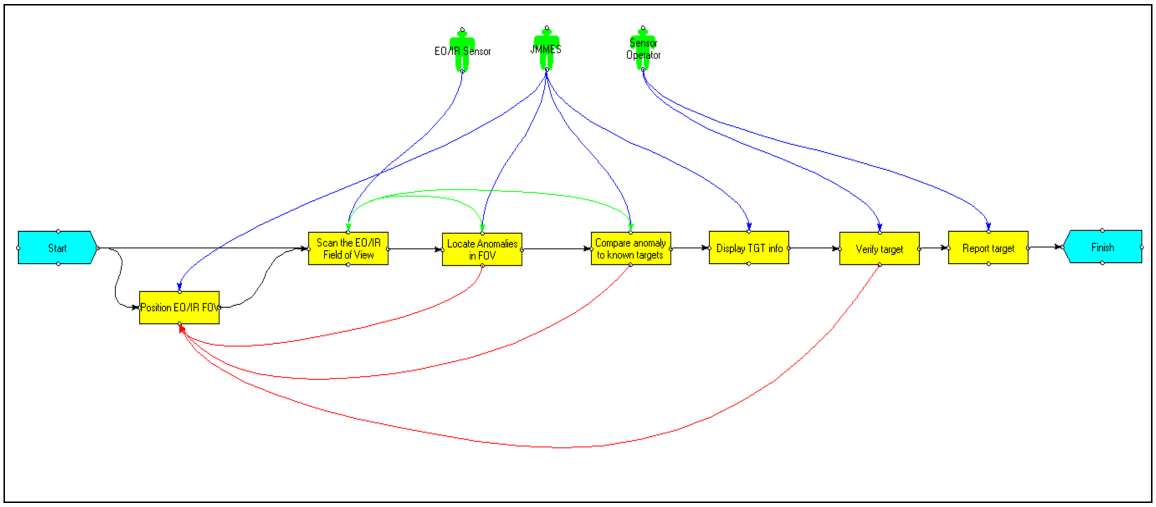

Figure 36. Alternative Case POW-ER Model

Alternative case time for task

Task		Time
Position EO/IR FOV		0.0058
Scan the EO/IR Field of View		0.0029
Locate Anomalies in FOV		0.0029
Compare anomaly to known targets		1.4000
Display TGT info		0.0029
Verify target		0.0058
Report target		0.0088
	Total Time	1.4292

Table 11. Alternative case task time required

4. Refine Model to Capture Lessons-Learned

The final step in the VDT process is to capture the lessons learned. A comparison of total time required to perform all task shows a reduction from 1.451 to 1.429. This translates to a 2% reduction in total time required,

despite the addition of two additional tasks. Table 12 shows side-by-side comparison of time for baseline and alternative cases.

Task	Time	Time	Position
Position EO/IR FOV	0.0146	0.0058	EO/IR sensor
Scan the EO/IR Field of View	0.0058	0.0029	JMMES
Locate Anomalies in FOV	0.0088	0.0029	JMMES / Operator
Compare anomaly to known targets	1.4000	1.4000	JMMES
Display TGT info	N/A	0.0029	JMMES
Verify target	N/A	0.0058	JMMES
Report target	0.0220	0.0088	Operator
Total	1.4512	1.4292	

Table 12. Baseline and Alternative Time Comparison

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V. CONCLUSIONS AND RECOMMENDATIONS

A. CONCLUSION

There were 13 JMMES system test-flights conducted during exercise Trident Warrior 2009, evaluating system capability in ASW, SUW, MIO, and SAR operations. Post-mission surveys were completed by the mission-area SMEs, allowing them to provide both a “score” of mission performance in a variety of predefined test-areas, as well as associated qualitative feedback on system performance. While the final individual numerical scores were not, by themselves, statistically significant, they allow for comparison between the different tested mission areas.

The results of survey information showed that in the tested COI areas, JMMES performed significantly better in MSAR operations as compared to SUW and ASW operations. When considering the more-detailed AOI areas, JMMES scored 49%, or average on the “0 to 4” scale utilized by the mission area SMEs. This indicates that in the opinion of the designated experts, JMMES performs at an adequate or average level as compared to currently employed systems.

The modeling provided in Chapter IV demonstrated that JMMES equipped manned aircraft system required less time in workflow and organization communication than non-JMMES manned aircraft system. The reduction in time required stemmed primarily from JMMES ability to store and replay captured imagery. For the non-JMMES model the operator consumed time zooming in on anomaly of interest or re-acquiring if the anomaly were no longer in the field of view.

Although the JMMES model showed reduction in time required, the reduction is minimal. While the model simulated only one iteration of a multi-step search process, the small percentage of time saved remains around 2% regardless of the number of iterations required. Although seemingly insignificant in difference, this time decrease can be multiplied over several aircraft. Mission flexibility is also greatly enhanced as neither the aircraft nor the equipment would require exchanging.

B. PROBLEMS

JMMES demonstrates technology that can be viewed as “disruptive” by the definition provided in Christensen and Overdorf study, “Meeting the Challenge of Disruptive Change.” Because of this fact, JMMES cannot be expected to perform well in a system for which it was not designed. The mission flights in TW09 were designed to assess military utility and not fully examine the potential capabilities.

C. RECOMMENDATIONS

While researching this thesis, we identified several item of future research for students who wish to develop them further. The items are listed.

1. Study the performance of JMMES’ additional system capability areas, specifically Counter Camouflage and Concealment, Illicit Crop Detection, Counter Improvised Explosive Device, Mine Counter Measures, and Combat Search and Rescue.

2. Analyze currently employed air search patterns to develop new search patterns that are optimized for JMMES detection capabilities across all mission areas.

3. Develop a simulation model to determine the optimal force composition of manned and unmanned systems on a surface combatant operating in the littoral regions.

4. Examine the performance of the multi-spectral electro-optic sensors in low-light conditions.

5. Conduct side-by-side field capability tests of JMMES and currently employed EO/IR systems to obtain quantifiable comparison data to evaluate system capability and performance.

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APPENDIX A. COI JMMES JCTD MUA ASSESSMENTS

A. COI-1 JMMES JCTD MUA ASSESSMENTS

	COI-1 JMMES JCTD MUA Assessments	Survey
1.1	Does the JMMES sensor suite improve the warfighter's situational awareness and level of reconnaissance in support of the eight user-prioritized mission areas?	C1.1
Situation Awareness		
	Qualitative	MA1 SA1 Coll1 ISR1-4
SA1	Does JMMES improve awareness of the target situation in the assigned surveillance area?	
SA2	Does the system provide battlefield understanding that is clear, sufficient, and timely?	SA2 Coll3 MA2
SA3	Rate the ease of maintaining SA across the AOR during search.	SA2
	Quantitative	
SA4	Number, fraction, of detected targets for which SA can be maintained during search.	
Level of Reconnaissance		
	Qualitative	
LR1	Does JMMES improve the level of reconnaissance in the assigned surveillance area?	ISR2
1.2	Does JMMES detect, classify, identify, and track camouflaged, and concealed objects fast enough to support tactical operations?	C1.2
Concealed and Camouflaged Objects		
	Qualitative	
CC1	Are the speeds of detection and identification of objects of interest sufficient for tactical operations?	ISR7
CC2	Can objects of interest be tracked during search?	ISR7
	Quantitative	
CC3	Determine the time between search initiation and initial detection of each target.	

CC4	Determine for each target the times between detection and identification.	
1.3	Do JMMES automated target recognition and automated cueing reduce manning requirements and increase the accuracy and/or certainty of target geolocation?	C1.3
Localize		
	Qualitative	
L1	Does automated detection improve the probability of detection?	AF2
L2	Does automated detection improve the ability/speed of the operator for identification?	AF5
L3	Does automated cueing produce excessive false alarms?	AF4
Workload		
	Qualitative	
W2	Does system automated detection reduce workload?	W2, AF3
W3	Does system alerting of the operator reduce workload?	W2, AF3

B. COI-2 JMMES JCTD MUA ASSESSMENTS

	COI-2 JMMES JCTD MUA Assessments	Survey
2.1 What is JMMES demonstrated capability in those eight user-prioritized mission areas?		
System Capabilities		
	Qualitative	C2.1
SC1	Is the ability to prosecute more than one mission area from a single flight a significant advantage to ISR operations?	ISR6
SC2	List those JMMES characteristics which positively/negatively impact the performance of tactical activities, by activity.	Coll5
SC3	List JMMES automated capabilities and whether each positively/negatively impact the performance of tactical activities, by activity.	Coll5 AF1-6
SC4	Do post-flight processing capabilities enhance JMMES mission support?	PF2,3
SC5	Does JMMES provide ISR capabilities that are not available from other assets (list)?	ISR3
	Quantitative	
SC6	Determine the probability of detection for known targets.	
SC7	Determine detection false alarm rate.	
SC8	Determine the time between search initiation and initial detection of each target.	
SC9	Determine for each target the times between detection > location > identification > classification.	
Information Quality		

	Qualitative	
IQ1	Does the GUI provide usable, clear, accurate, relevant views?	HS4
IQ2	Are high-power zoom images usable, clear?	AF1
IQ3	For each advanced image processing capability that is available rate the image effectiveness and whether the image is usable, clear, accurate registration, relevant.	V1-10
2.2	How operationally effective is the JMMES capability?	
ISR Activity Support Effectiveness		
	Qualitative	C2.2
SE1	Rate JMMES effectiveness supporting: Collection Planning, Collection Tasking, Search, Detect, Identify, and Track. for the attributes: effectiveness, improvement, speed, accuracy, sufficiency.	ISR1,2 Coll1-5
SE2	Can stationary/moving objects be tracked?	TT1
SE3	Is operator executed tracking persistent, accurate?	TT2
SE4	Is automated system tracking persistent, accurate?	TT3
SE5	Does JMMES provide improved Detection, Identification?	Coll1
SE6	Rate JMMES accuracy supporting Detect, Identify?	Coll4
SE7	Rate JMMES speed supporting Detect, Identify?	Coll3
	Quantitative	
SE8	Determine the time between search initiation and initial detection of each target.	

SE9	Determine for each target the times between detection and identification.	
SE10	Determine the location error for each target.	
2.3 Does JMMES architecture interface with current and future fielded equipment?		
	No determination will be made.	
2.4 Is JMMES interoperable with existing sensor systems as related to intelligence Tasking, Processing, Exploitation, and Dissemination (TPED)?		
ISR Interoperability		
	Qualitative	C2.4
In1	Rate the ease of integrating JMMES with other ISR assets for collection tasking.	ISR4
In2	Are there any incompatibilities between JMMES and other assets ISR information? (list)	ISR4

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C. COI-3 JMMES JCTD MUA ASSESSMENTS

COI-3 JMMES JCTD MUA Assessments		Survey
3.1	Is the JMMES capability operationally suitable for the eight user-prioritized mission areas?	C3.1
Mission Suitability		
	Qualitative	
MS1	Rate JMMES suitability for supporting this ISR mission.	MA1,2,4
MS2	Determine any mission required functions that cannot be provided by the system.	MA4
MS3	Rate the reliability of the system.	SM6
	Quantitative	
MS4	Determine the fraction of flight time for which the system is down.	
MS5	Log system performance for duration of the mission.	
3.2	Is JMMES reliable, trainable, supportable, and maintainable?	C3.2
System Management		
	Qualitative	
SM1	Rate system management efficiency.	SM1
SM2	Rate sensor management efficiency.	SM2
SM3	Rate system status reports effectiveness (accuracy, clarity, sufficiency).	SM4

SM4	Rate search coverage map effectiveness (accuracy, clarity, sufficiency).	SM5
SM5	Rate system configuration ease/efficiency: pre-flight, in-flight, recovery after failure.	SM3
SM6	Rate sensor tasking/re-tasking ease/efficiency.	SM3
SM7	Rate the ease/efficiency of in-flight re-configuration for a new mission area.	W5
	Quantitative	
SM8	Fraction of flight time spent in system management.	
Human System Interaction		
	Qualitative	
HS1	List JMMES training received prior to the test.	
HS2	Which features of the system are easiest/most difficult to learn to operate?	HS3
HS3	Rate how well the operator can maintain their full capabilities during a flight.	HS5
HS4	Rate the GUI for activity support effectiveness.	HS4, W6
HS5	Rate how easy JMMES is to use.	HS2
HS6	Was disorientation or concentration fatigue a factor in JMMES usage? If so, explain cause.	HS3
HS7	Rate JMMES ease/efficiency for the following operator actions: GUI management, sensor management, turret control, view management.	HS2,7 W6

HS8	Rate JMMES ease/clarity for the following operator situation awareness components: field of view with respect to surroundings, sensor pointing with respect to aircraft, sensor pointing with respect to geography, target status, scan area coverage.	HS2,6
	Quantitative	
HS9	Log instances of induced system malfunction and task execution cause.	
Operator Workload		
	Qualitative	
OW1	Does JMMES reduce operator workload for ISR collection?	W1,4,6
OW4	Is operating JMMES efficient?	W4-6
	Quantitative	
OW5	Log the time spent in each activity during a collection flight.	
OW6	Log the time spent planning a mission.	
OW7	Log the time spent setting up JMMES for a mission.	

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APPENDIX B. TW09 JMMES SURVEY

Mission Area_____________ Scenario_______________ Master Survey (JMMES and M-VIVID)

Date_______________ Name_______________

Use the check boxes to provide an answer for each question, Y/N or the scale for a particular system attribute.

Use the space below each question for comments, especially why for any y/n answer.

0=poor, 4=superior; COI Correlation; Oper; SME; Post-Flt

		Y	N	0	1	2	3	4	Not Obs	1.1	1.2	1.3	2.1	2.2	2.4	3.1	3.2
	Mission Area Support																
MA1	Rate how the System capability compares to current capabilities for this Mission Area.			0	1	2	3	4		X						X	
MA2	Rate the support provided for successful completion of this Mission Area's activities and also rate the below individual support factors.			0	1	2	3	4								X	
	Speed of activity/task completion			0	1	2	3	4									
	Information sufficiency/completeness			0	1	2	3	4									
	Information quality			0	1	2	3	4									
MA3	Are there any factors that reduce JMMES suitability to support this mission area? If so, list and rate the magnitude of the difficulty.	Y	N													X	
	Factor-1			0	1	2	3	4									
	Factor-2			0	1	2	3	4									
	Factor-3			0	1	2	3	4									
	Factor-4			0	1	2	3	4									
	ISR Operations Support																
ISR1	Rate the systems coverage capabilities for a day's ISR missions compared to current capabilities.			0	1	2	3	4		X				X			
ISR2	Does the system provide ISR **collection/surveillance** capabilities that are not available from other assets? If so, list and rate effectiveness.	Y	N										X				
	Capability-1			0	1	2	3	4									
	Capability-2			0	1	2	3	4									
	Capability-3			0	1	2	3	4									
	Capability-4			0	1	2	3	4									
ISR3	Does the system provide ISR **information** that is not available from other assets? If so, list and rate information utility.	Y	N							X							
	Information-1			0	1	2	3	4									
	Information-2			0	1	2	3	4									
	Information-3			0	1	2	3	4									
	Information-4			0	1	2	3	4									
ISR4	Rate the overall **interoperability** of JMMES with other ISR systems. List and explain any incompatibilities.			0	1	2	3	4							X		
	Incompatibility-1																
	Incompatibility-2																
	Incompatibility-3																
	Incompatibility-4																
ISR5	Does the capability to collect information for multiple missions provide ISR operations benefit?	Y	N										X				
ISR6	Rate the following factors for prosecuting multiple mission areas during a single flight.																
	Speed of changing missions			0	1	2	3	4									
	Efficiency for changing missions software			0	1	2	3	4									
	Efficiency for changing missions hardware settings			0	1	2	3	4									
	Ease of switching SA from one mission area to the next			0	1	2	3	4									
ISR7	Rate how the System capability compares to current capabilities for detection of objects of interest. Rate the following detection factors.			0	1	2	3	4			X						
	Detection speed			0	1	2	3	4									
	Operator identification/recognition speed			0	1	2	3	4									
	Ease/Efficiency of operator identification/recognition			0	1	2	3	4									
	Tracking capabilities			0	1	2	3	4									

	Target Situation Awareness							
SA1	Rate the System's capabilities to provide target Situation Awareness in a flight's assigned search area compared to current capabilities.		0 1 2 3 4	X				
SA2	Can you maintain Situation Awareness over the full search area during search? Rate the following SA attributes.		Y N	X				
	Situation clarity		0 1 2 3 4					
	SA sufficiency		0 1 2 3 4					
	Timeliness of developing SA		0 1 2 3 4					
	Ease of maintaining SA across the full area during search		0 1 2 3 4					
	ISR Collection Activities							
	The following questions rate System performance for the three principal ISR collection activities.							
Coll1	Rate how the System capability compares to current capabilities for	Search	0 1 2 3 4	X			X	
		Detection	0 1 2 3 4					
		Operator ID	0 1 2 3 4					
Coll2	Rate the overall effectivness of the System for	Search	0 1 2 3 4				X	
		Detection	0 1 2 3 4					
		Operator ID	0 1 2 3 4					
Coll3	Rate the speed of performing each activity with the System	Search	0 1 2 3 4	X			X	
		Detection	0 1 2 3 4					
		Operator ID	0 1 2 3 4					
Coll4	Rate the accuracy of performing the activity	Search	0 1 2 3 4				X	
		Detection	0 1 2 3 4					
		Operator ID	0 1 2 3 4					
Coll5	List any System characteristic/capability that significantly impacts ISR collection effectiveness, and circle whether positively (P) or negatively (N).					X		
	Characteristic-1 P N							
	Characteristic-2 P N							
	Characteristic-3 P N							
	Characteristic-4 P N							
	Target Tracking							
TT1	Can object location (tracking) be maintained during search for	Stationary Objects	Y N				X	
		Moving Objects	Y N					
TT2	Can the operator provide object location (tracking) that is	Persistent	Y N				X	
		Accurate	Y N					
TT3	Can the System provide automated object location (tracking) that is	Persistent	Y N				X	
		Accurate	Y N					
	Planning and Operator Workloads							
W1	Rate how the System operator workload compares with current ISR assets.		0 1 2 3 4					X
W2	Are there **automated** System features that reduce operator workload? List and rate the features.		Y N		X			X
	Feature-1		0 1 2 3 4					
	Feature-2		0 1 2 3 4					
	Feature-3		0 1 2 3 4					
	Feature-4		0 1 2 3 4					
W3	List other features of the system that impact operator workload and circle whether positively (P) or negatively (N).				X			X
	Feature-1 P N							
	Feature-2 P N							
	Feature-3 P N							
	Feature-4 P N							

W4	Estimate the % of operational flight time the operator spent on each of the following activities (there are overlaps so will not add to 100%).											X
	Sensor configuration/management	% ____										
	GUI configuration/management	% ____										
	Turret adjustment/management	% ____										
	Search	% ____										
	Actively processing targets	% ____										
W5	Workload Comments											X
	In-Flight System Management											
SM1	Rate system management efficiency.				0	1	2	3	4			X
SM2	Rate in-flight sensor management efficiency.				0	1	2	3	4			X
SM3	Rate system configuration efficiency (pre-planned or after system failure).				0	1	2	3	4			X
SM4	Rate system status reports for how	Easily Obtained	Y	N								X
		Accurate	Y	N								
		Clear	Y	N								
		Sufficient	Y	N								
SM5	Rate the search status/coverage presentation for how	Easily Obtained			0	1	2	3	4			X
		Accurate			0	1	2	3	4			
		Clear			0	1	2	3	4			
		Sufficient			0	1	2	3	4			
SM6	Rate System reliability. Estimate % of time down_____%				0	1	2	3	4		X	X
	Human-System Interaction											
HS1	List the training you had on the System prior to this exercise.											
HS2	Rate how easy the System is to operate. List features that are easy/difficult, circle E or D.				0	1	2	3	4			X
	Feature-1 E D											
	Feature-2 E D											
	Feature-3 E D											
	Feature-4 E D											
HS3	Rate how easy the System is to learn. List features that are easy/difficult, circle E or D.				0	1	2	3	4			X
	Feature-1 E D											
	Feature-2 E D											
	Feature-3 E D											
	Feature-4 E D											
HS4	Rate the GUI for	Usability			0	1	2	3	4	X		X
		Clarity			0	1	2	3	4			
		Accuracy			0	1	2	3	4			
		Relevance			0	1	2	3	4			
HS5	Rate how well operator capabilities can be maintained during a flight. List any factors, such as disorientation or fatigue, that impacted capabilities.				0	1	2	3	4			X
	Factor-1											
	Factor-2											
	Factor-3											
HS6	Rate the ease of maintaining awareness of	Field of View			0	1	2	3	4			X
		Sensor Pointing			0	1	2	3	4			
		Target Status			0	1	2	3	4			
		Scan Coverage			0	1	2	3	4			

HS7	Rate the ease of performing	Sensor Mgmt		0 1 2 3 4
		Turret Control		0 1 2 3 4
		View Mgmt		0 1 2 3 4
HS8	Are there instances where performing System tasks caused a system malfunction? If so list the operation that caused the malfunction.		Y N	
	Incident-1			
	Incident-2			
	Incident-3			
	Automated Features			
AF1	Indicate (Y/N) System automated features that are operational and rate the effectiveness of those that are.			
	Auto-Detection		Y N	0 1 2 3 4
	Contact Look-Back		Y N	0 1 2 3 4
	Other-1			0 1 2 3 4
	Other-2			0 1 2 3 4
	Other-3			0 1 2 3 4
AF2	Indicate (Y/N) whether automated detection improves probability of detection. If Y, rate the improvement.		Y N	0 1 2 3 4
AF3	Indicate (Y/N) whether automated detection reduces workload during search. If Y, rate the reduction.		Y N	0 1 2 3 4
AF4	Does automated detection produce an excessive number of false alarms?		Y N	
AF5	Indicate (Y/N) whether automated detection improves the ability/speed of the operator for identifying objects. If Y, rate the improvement.		Y N	0 1 2 3 4
	Views, Images, and Processing			
The System contains advanced image and processeing features. Indicate whether a feature is available (Y/N), and rate each that is available for its contribution to target detection, location, and ID. Provide comments if appropriate.				
V1	Multi-image stitched images		Y N	0 1 2 3 4
V2	Multi-sensor integration images		Y N	0 1 2 3 4
V3	Multi-band images		Y N	0 1 2 3 4
V4	High-power zoom images for		Y N	0 1 2 3 4
V5	Spectral filter views		Y N	0 1 2 3 4
V6	Spatial match filter views		Y N	0 1 2 3 4
V7	Environmental suppression views		Y N	0 1 2 3 4
V8	Multi-band target/background discrimination views		Y N	0 1 2 3 4
V10	List and rate other advanced processing capabilities that aid in performing target assessment.			
	Capability-1			0 1 2 3 4
	Capability-2			0 1 2 3 4
	Capability-3			0 1 2 3 4
	Capability-4			0 1 2 3 4
	Post-Flight Products			
PF1	Does post-flight processing contribute to successful completion of the mission?		Y N	
PF2	Does post-flight processing provide target information that was not obtained during the flight	Additional Targets	Y N	
		Identification	Y N	
		Location	Y N	
PF3	Rate the listed factors for post-flight products. You are judging the support they provide for the mission area's military operations.	Timely		0 1 2 3 4
		Usable		0 1 2 3 4
		Clarity		0 1 2 3 4
		Complete		0 1 2 3 4
		Relevance		0 1 2 3 4
PF4	Rate the accuracy of target location by comparing ground truth with	contact log		0 1 2 3 4
		post-flight analysis		0 1 2 3 4

Critical Operational Issues

Critical Operational Issue questions have been specified and are listed below. Answer the question y/n and rate the degree of System success for that Issue. These are overarching summaries. Comments will be needed.

C1.1	Does the System sensor suite improve the warfighter's situational awareness and level of reconnaissance in support of the eight user-prioritized mission areas?	Y	N	0	1	2	3	4	X								
C1.2	Does the System detect, classify, identify, and track camouflaged, and concealed objects fast enough to support tactical operations?	Y	N	0	1	2	3	4		X							
C1.3	Do System automated target recognition and automated cueing reduce manning requirements and increase the accuracy and/or certainty of target geolocation?	Y	N	0	1	2	3	4			X						
C2.1	What is System demonstrated capability in those eight user-prioritized mission areas?			0	1	2	3	4				X					
C2.2	How operationally effective is the System capability?			0	1	2	3	4					X				
C2.4	Is the System interoperable with existing sensor systems as related to intelligence Tasking, Processing, Exploitation, and Dissemination (TPED)?	Y	N	0	1	2	3	4						X			
C3.1	Is the System capability operationally suitable for the eight user-prioritized mission areas?	Y	N	0	1	2	3	4							X		
C3.2	Is JMMES reliable, trainable, supportable, and maintainable?	Y	N	0	1	2	3	4								X	

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APPENDIX C. AOI SURVEY RESULTS

A. SUMMARY RATINGS

ASW JMMES SME AoI Summary Ratings	
Area of Interest	Rating
Mission Area Support Summary Rating	43%
ISR Operations Support Summary Rating	44%
Target Situation Awareness Summary Rating	25%
ISR Collection Activities Summary Rating	41%
Planning & Operator Workloads	52%
In-Flight System Management Summary Rating	55%
Human-System Interaction Summary Rating	60%
Automated Features Summary Rating	58%

MSAR JMMES SME AoI Summary Ratings	
Area of Interest	Rating
Mission Area Support Summary Rating	50%
ISR Operations Support Summary Rating	59%
Target Situation Awareness Summary Rating	44%
ISR Collection Activities Summary Rating	57%
Planning & Operator Workload	42%
In-Flight System Management Summary Rating	60%
Human-System Interaction Summary Rating	59%
Automated Features Summary Rating	75%

SUW JMMES SME AoI Summary Ratings	
Area of Interest	Rating
Mission Area Support Summary Rating	35%
ISR Operations Support Summary Rating	36%
Target Situation Awareness Summary Rating	55%
ISR Collection Activities Summary Rating	33%
Planning & Operator Workload	33%
In-Flight System Management Summary Rating	66%
Human-System Interaction Summary Rating	61%
Automated Features Summary Rating	30%

B. ASW AOI RESULTS

	Miss-Area Support				
	Rating Level				
	0	1	2	3	4
50					
40					
30					
20					
10					
0					
	4	43	30	17	4

	ISR Ops Support				
	Rating Level				
	0	1	2	3	4
50					
40					
30					
20					
10					
0					
	13	36	21	21	9

	Target SA				
	Rating Level				
	0	1	2	3	4
50					
40					
30					
20					
10					
0					
	42	21	32	5	0

	ISR Collect Activities				
	Rating Level				
	0	1	2	3	4
50					
40					
30					
20					
10					
0					
	19	37	16	17	11

	Workload				
	Rating Level				
	0	1	2	3	4
50					
40					
30					
20					
10					
0					
	0	31	31	38	0

	In-Flight Syst Mgmt				
	Rating Level				
	0	1	2	3	4
50					
40					
30					
20					
10					
0					
	33	33	17	17	0

	Human-System							Automated Features				
	Rating Level							Rating Level				
	0	1	2	3	4			0	1	2	3	4
50							50					
40							40					
30							30					
20							20					
10							10					
0							0					
	0	17	29	55	0			0	26	26	37	11

C. MSAR AOI RESULTS

	Miss-Area Support				
	Rating Level				
	0	1	2	3	4
50					
40					
30					
20					
10					
0					
	0	29	43	29	0

	ISR Ops Support				
	Rating Level				
	0	1	2	3	4
50					
40					
30					
20					
10					
0					
	0	36	18	18	27

	Target SA				
	Rating Level				
	0	1	2	3	4
50					
40					
30					
20					
10					
0					
	0	22	78	0	0

	ISR Collect Activities				
	Rating Level				
	0	1	2	3	4
50					
40					
30					
20					
10					
0					
	0	21	38	33	8

	Workload				
	Rating Level				
	0	1	2	3	4
50					
40					
30					
20					
10					
0					
	0	67	0	33	0

	In-Flight Syst Mgmt				
	Rating Level				
	0	1	2	3	4
50					
40					
30					
20					
10					
0					
	0	17	25	58	0

	Human-System							Automated Features				
	Rating Level							Rating Level				
	0	1	2	3	4			0	1	2	3	4
50							50					
40							40					
30							30					
20							20					
10							10					
0							0					
	0	25	25	38	13			0	0	17	67	0

D. SUW AOI RESULTS

	Miss-Area Support				
	Rating Level				
	0	1	2	3	4
100					
80					
60					
40					
20					
0					
	0	80	0	20	0

	ISR Ops Support				
	Rating Level				
	0	1	2	3	4
100					
80					
60					
40					
20					
0					
	7	14	57	29	0

	Target SA				
	Rating Level				
	0	1	2	3	4
100					
80					
60					
40					
20					
0					
	0	20	40	40	0

	ISR Collect Activities				
	Rating Level				
	0	1	2	3	4
100					
80					
60					
40					
20					
0					
	0	67	33	0	0

	Workload				
	Rating Level				
	0	1	2	3	4
100					
80					
60					
40					
20					
0					
	33	0	67	0	0

	In-Flight Syst Mgmt				
	Rating Level				
	0	1	2	3	4
100					
80					
60					
40					
20					
0					
	0	25	0	63	13

	Human-System							Automated Features				
	Rating Level							Rating Level				
	0	1	2	3	4			0	1	2	3	4
100							100					
80							80					
60							60					
40							40					
20							20					
0							0					
	0	22	22	44	11			0	80	20	0	0

APPENDIX D. BASELINE MODEL PROPERTIES

Baseline Position Properties

	EO/IR Sensor	Operator
Culture	Generic	Generic
Role	st	pm
App Experience	low	low
CClt Experience	medium	medium
FTE	1	1
Salary	0	0
Skill Ratings	Identify TGT in Noise [low] Generic [medium] Differentiate specific TGTs [low]	Identify TGT in Noise [low] Generic [low] Differentiate specific TGTs [medium] Position sensor [medium]

Baseline Task Properties

	Position EO/IR FOV	Scan the EO/IR FOV	Locate anomalies in FOV	Compare anomaly to known targets	Report Tartet
Errot	3 Minutes	1 Minute	1	3 Minutes	2 Minutes
Effort Type	work-duration	work-duration	work-duration	max-duration	work-volume
Required Skill	Position Sensor	Generic	Identify TGT in noise	Differentiate specific TGT	Generic
Learning Days	100	100	100	100	100
Priority	high	medium	medium	low	medium
Requirement Complexity	medium	low	high	high	low
Solution Complexity	high	low	high	high	low
Uncertainty	medium	low	high	high	low
Fixed Cost	0	0	0	0	0

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APPENDIX E. ALTERNATE CASE MODEL PROPERTIES

Alternate Position Properties

	EO/IR Sensor	JMMES	Operator
Culture	Generic	Genric	Generic
Role	st	st	pm
App Experience	low	medium	low
CCIt Experience	medium	medium	medium
FTE	1	1	1
Salary	0	50	0
Skill Ratings	Identify TGT in Noise [low] Generic [medium] Differentiate specific TGTs [low]	Identify TGT in Noise [high] Generic [medium] Differentiate specific TGTs [medium] Position sensor [high]	Identify TGT in Noise [low] Generic [low] Differentiate specific TGTs [medium] Position sensor [medium]

Alternate Task Properties

	Position EO/IR FOV	Scan the EO/IR FOV	Locate anomalies in FOV	Compare anomaly to known targets	Display TGT info	Verify target	Report target
Errot	3 Minutes	1 Minute	1	3 Minutes	2 Minutes	2 Minutes	2 Minutes
Effort Type	work-duration	work-duration	work-duration	max-duration	work-volume	work-volume	work-volume
Required Skill	Position Sensor	Generic	Identify TGT in noise	Differentiate specific TGT	Generic	ifferentiate specific TGT	Generic
Learning Days	100	100	100	100	100	100	100
Priority	high	medium	medium	low	medium	medium	medium
Requirement Complexity	medium	low	high	high	low	medium	low
Solution Complexity	high	low	high	high	low	medium	low
Uncertainty	medium	low	high	high	low	medium	low
Fixed Cost	0	0	0	0	0	0	0

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